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THE DISTRIBUTION OF SOME CHEMICAL ELEMENTS BETWEEN DISSOLVED AND PARTICULATE PHASES IN THE OCEAN

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2. Research Period: August 1, 1975 - July 31, 1976

3. Introduction:

Our work during the past year has concentrated on three areas:

1) Completion of the studies of Pb^{210} and Po^{210} in both dissolved and particulate states in a transect of the equatorial Northern Atlantic Ocean.

2) Continued studies on the particulate matter, Po^{210} and Pb^{210} distributions in the Gulf of Maine.

3) Preparations for our participation in the 'Fladen Ground Experiment 1976' (FLEX 76).

DISCLAIMER

1. Distribution of Lead-210 and Polonium-210 between soluble and particulate phases in the Deep North Equatorial Atlantic Ocean.

During the past year we have completed our investigations of Pb-210 (t1/2=22 yr) and Po-210 (t1/2=138 d) distributions in sea water and suspended matter samples collected during Cruise 32 of the F/S METEOR. Completed descriptions of the results are given in later sections of this report and in the accompanying thesis of Dr. M. P. Bacon.

The principal objective of these studies is to further understand the mechanisms and rates of scavenging and transport of materials by particulate matter in the sea. The distribution of a substance in the ocean is influenced by the mechanisms of its introduction and removal, by water motions and by the extent of its incorporation and transport in particulate phases. Measurements of both natural and artificial radionuclides offer some unique insights into these processes.

The natural radiotracers Pb-210 and Po-210 were chosen for study because earlier reports indicated that their half-lives are long enough for measurable radioactive disequilibria to be maintained by processes operating in the oceans, but short enough that their activities in sea water can be measured with reasonable ease. Further, these tracers are supplied to the ocean principally by in-situ decay of their parent nuclides (except for Pb^{210} in the mixed layer, most of which is formed in the atmosphere), and their rates of supply can thus be accurately determined.

The distribution of ^{210}Pb and ^{210}Po in dissolved (<0.4 micron) and particulate (>0.4 micron) phases has been measured at ten stations in the tropical and eastern North Atlantic and at two stations in the Pacific. Both radionuclides occur principally in the dissolved phase. Unsupported ^{210}Pb activities, maintained by flux from the atmosphere, are present in the surface mixed layer and penetrate into the thermocline to depths of about 500 m. Dissolved ^{210}Po is ordinarily present in the mixed layer at less than equilibrium concentrations, suggesting rapid biological removal of this nuclide. Particulate matter is enriched in ^{210}Po, with $^{210}Po/^{210}Pb$ activity ratios greater than 1.0, similar to those reported for phytoplankton. Box-model calculations yield a 2.5 y residence time for ^{210}Pb and a 0.6 y residence time for ^{210}Po in the mixed layer. These residence times are considerably longer than the time calculated for turnover of particles in the mixed layer (about 0.1 y). At depths of 100-300 m, ^{210}Po maxima occur and unsupported ^{210}Po is frequently present. Calculations indicate that at least 50% of the ^{210}Po removed from the mixed layer is recycled within the thermocline. Similar calculations for ^{210}Pb suggest much lower recycling efficiencies.

Comparison of the ^{210}Pb distribution with the reported distribution of ^{226}Ra at nearby GEOSECS stations has confirmed the widespread existence of a $^{210}Pb/^{226}Ra$ disequilibrium in the deep sea. Vertical profiles of particulate ^{210}Pb were used to test the hypothesis that ^{210}Pb is removed from deep water by in situ scavenging. With the exception of one profile taken near the Mid-Atlantic Ridge, significant vertical

gradients in particulate ^{210}Pb concentration were not observed, and it is necessary to invoke exceptionally high particle sinking velocities to account for the inferred ^{210}Pb flux. It is proposed instead that an additional sink for ^{210}Pb in the deep sea must be sought. Estimates of the dissolved $^{210}Pb/^{226}Ra$ activity ratio at depths greater than 1,000 m range from 0.2 to 0.8 and reveal a systematic increase, in both vertical and horizontal directions, with increasing distance from the sea floor. This observation implies rapid scavenging of ^{210}Pb at the sediment-water interface and is consistent with a horizontal eddy diffusivity of 3-6 x 10^7 cm^2/s. The more reactive element Po, on the other hand, shows evidence of rapid in situ scavenging. In filtered sea water, ^{210}Po is deficient, on the average, by ca. 10% relative to ^{210}Pb; a corresponding enrichment is found in the particulate phase. Total inventories of ^{210}Pb and ^{210}Po over the entire water column, however, show no significant departure from secular equilibrium.

2. Polonium-210 and Lead-210 disequilibria in the Gulf of Maine

Introduction

As part of a continuing effort on the study of element partitioning between dissolved and particulate phases in sea water we initiated, last year, a program to determine the distribution of particulate and dissolved Pb^{210} and Po^{210} in the Gulf of Maine.

The Murray-Wilkinson Basin in the Gulf of Maine is a unique area on the eastern continental shelf of the United States because of its relatively stable deep water structure. Deep water in the Gulf originates in intermittent flows through the Northeast channel. This water is principally slope water and coastal water of Labrador origin. The deep water temperature and salinity responds to variations in the compositions and relative proportions of these waters entering the Northeast channel. However, Colton (1968) has shown that the Murray-Wilkinson Basin bottom water is least affected by these intermittent variations. Further, Colton and Stoddard (1973) have shown that the average bottom water temperatures encountered in the deep part of the Murray-Wilkinson Basin tend to be relatively constant.

Renewal of deep water in the basins of the Gulf of Maine occurs both by input from the Northeast channel and by annual overturn. However, the stability of the deep water in the Murray-Wilkinson Basin indicates that the annual overturn following the breakdown of the summer thermocline rarely affects the deep water. Hydrographic data from Ketchum (1968) and Spencer and Sachs (1970) indicated that for the years 1966-1967 the

depth of the surface overturn during the winter was to about 75 to 85 meters. During our cruise in January 1975 we found a similar depth of overturn.

These data, together with supportive data of nutrient and oxygen concentrations, suggest that the renewal time of deep water in the Murray-Wilkinson Basin may be considerably in excess of one year.

The stability of the deep water column is important for it gives us the opportunity to disentangle effects due to short time scale events that would not be possible in other shelf areas.

The Murray-Wilkinson Basin is an elongated (NNW-SSE) depression in the sea floor, about 80 miles long, which reaches a maximum depth of about 285 meters. It is open to the east and southeast, where the Rodgers passage and a passage to the Franklin Basin form sills of about 185 meters depth. To the north, a channel connected to the Platts Basin has a sill of about 170 meters. The Franklin Basin is a southwestward extension of the Georges Basin and is connected to the open North Atlantic Ocean with sills deeper than 200m. The deep part of the basin is split by the Wilkinson divide, a ridge of about 250 meters depth which separates the Wilkinson and Murray Basins.

During ATLANTIS II Cruise 86 in January 1975 we collected hydrographic data and water and particulate matter samples for Pb^{210}, Po^{210} and stable trace element studies. At this time we have completed the radioisotope analyses and this report summarizes our preliminary observations.

Detailed hydrographic data was presented in last year's report (Spencer, 1975) but a brief summary is included here.

Hydrography of the Murray-Wilkinson Basin

During January 1975 the salinity and temperature data collected show that conditions existing now in the deep Gulf of Maine are somewhat different from those of previous decades. A succession of mild winters, particularly 1973-74 and 1974-75 has led to warmer water compared with earlier years.

The salinity and temperature distributions along the section identified A-A^1, B-B^1 and C-C^1 in Figure 1 are given in Figures 2 to 7. A composite plot of potential temperature versus salinity is given in Figure 8 and this shows that with the exception of three of the most easterly stations, there is a very limited vertical range in temperature (between about 6.6°C and 7.8°C) and that most stations are characterized by a major inversion in the temperature profile. Surface water, with a density of about 26.10σ_τ had a range of temperature from about 6.98°C to 7.70°C and a salinity range from 33.165‰ to 33.402‰. The two easternmost stations (2141 and 2142) have the warmest surface water and mid-water warm cores that reach temperatures of 8.69°C. These stations are closer to the central region of the Gulf of Maine and probably represent a residual of "summer" water that has been less well mixed with the colder fresher water in the major gyre. A "residual" warm water core is present at about 140m depth in all of the stations (see Figures 2, 4 and 6). In the deep water a major feature is a cold

water core which is most pronounced in the southern regions of the basin. At stations 2144, 2149 and 2154, temperature minima of 6.60°C, 6.77°C and 6.65°C occur respectively at depths of 156m, 164m and 160m, with salinities of 33.657‰, 33.798‰ and 33.700‰. This cold layer persists throughout the basin at about 180 to 200m depth but is at a maximum thickness at the southern end. Figure 6 shows that at the northern end of the basin, the cold water core is thickest toward the western slope. This suggests that the cold water core may be part of the major gyre and represent a mixture of Labrador Coastal Water and Slope Water advecting in from the Franklin Basin. Although a narrow passage with a depth of about 185m connects the Wilkinson and Franklin Basins, there is a very broad sill with a depth of about 160m corresponding to the depth of the cold water core in the south and east.

Below 200m, in the deepest portions of the basin, the bottom water has temperatures from 7.20°C to 7.35°C and salinities from 34.080‰ to 34.165‰. Bottom water temperatures of about 7.2°C are principally restricted to the Wilkinson Basin. In the Murray Basin, such temperatures occur only in the very deepest portions toward the southern end. This is undoubtedly due to the more extensive mixing with the cold water core immediately above and the presence of the Wilkinson divide which restricts the circulation of the bottom water. Station 2142 is unique in having bottom water temperatures of 7.85°C at 205 meters with salinities of 34.270‰. This salty warm water is probably connected to the deep warm water core of station 2141 and probably represents deep water from the

Northeast Channel of predominantly Slope Water origin with a salinity of about 35‰ and temperature of about 9°C (McLellan, 1957).

The relationships between salinity and both dissolved oxygen and silicate are shown in Figure 9. Each relationship may be described by essentially three linear sections representative of 1) mixing between the high oxygen and low silica surface water and warm mid-water core of salinity 33.5‰, 2) mixing between the warm water core and the cold water core of salinity 33.75‰ where a marked decrease in oxygen and increase in silicate are observed and 3) mixing between the cold water core and the bottom water of slightly lower oxygen and higher silicate. The oxygen and silicate concentrations of the cold water core are consistent with its origin in a mixture of Labrador Coastal Water and Slope Water. The bottom water has lower oxygen and higher silicate than would be expected in either the Labrador Coastal Water or Slope Water and may indicate some in situ oxidation, during a relatively long residence time of the bottom water in the Gulf of Maine.

Lead-210 and Polonium-210 Distributions

Sampling and Analytical Methods

Water and particulate matter samples for Pb^{210} and Po^{210} were collected at stations 2122, 2138 and 2151 using methods described by Bacon (1975). The analytical procedures also followed those described by Bacon (1975).

The plankton samples are subsamples of 20 minute surface plankton tows taken using a 158μ mesh net of #10 nylon bolting cloth. The plankton

were stored in one quart glass canning jars and preserved by freezing. The samples were filtered through preweighed Whatman filters. The filters and plankton were weighed, dried overnight and reweighed to obtain wet and dry net weights. The plankton was then recombined with the fluid portions for subsequent digestion and analysis. For station 2128 the fluid and solid portions were analyzed separately.

The samples were spiked with Po^{208} tracer and stable lead carrier and dissolved using a mixed nitric-perchloric-hydrofluoric acid digestion with 150-30-10 mls of acid respectively. The digestion was allowed to proceed slowly for 3 days and was taken to fuming perchloric acid to insure complete sample dissolution and to drive off the excess nitric acid. The samples were diluted with 2N HCl and plated on silver in the usual way from 200 ml of solution. It was found that this plating removed from 88 to 98 percent of the polonium. The samples were plated again a few days later to remove the residual polonium. The sums of the efficiencies from the two platings were from .996 to 1.069. It was noted that the ^{210}Po to ^{208}Po ratio was nearly identical for both platings of the same sample.

Data

Lead-210 and polonium-210 were determined in 20 liter unfiltered water samples for a total analyses and in samples collected from a separate 20 liter water sample by filtration through 0.45μ Nuclepore filters. The data, together with relevant hydrographic and particulate

matter data, are given in Table 1. Table 2 gives derived values of the "dissolved" isotopes from the differences between the "total" and "particulate" data in Table 1. At one station (2138) we have determined the concentrations in two filtered sea water samples to compare with the derived "dissolved" concentrations. For both lead-210 and polonium-210 it is clear that, within the error limits of our technique, these values are the same. Data from the plankton tows at stations 2122, 2128 and 2135 are given in Table 3.

Vertical profiles of the dissolved lead and polonium and the particulate lead and polonium are given in Figures 10 and 11 respectively. The salinity and temperature profiles at the same stations are given in Figure 12 while the dissolved oxygen, silicate and inorganic phosphate distributions appear in Figure 13.

From these profiles it is apparent that the surface layer which varies from 40 to 80 meters deep has virtually constant dissolved lead and polonium concentrations of about 1.6 dpm $100\ell^{-1}$ and similarly constant particulate lead and polonium concentrations of about 1.15 dpm $100\ell^{-1}$. In the warm water core from 80 to 150 meters, which is characterized by a slight decrease in oxygen and increase in phosphate, the dissolved Pb^{210} decreases to less than 1 dpm $100\ell^{-1}$ while the dissolved Po^{210} increases to a maximum of 2.3 dpm $100\ell^{-1}$ at about 120 m. In this same layer the particulate Pb^{210} increases slightly to about 1.35 dpm $100\ell^{-1}$ while the particulate Po^{210} remains about constant. The major pycnocline between the warm and cold water cores from 150 to 180

meters is characterized by decreases in all four parameters. The cold water core appears to form slight minima in both dissolved and particulate Pb^{210} while the Po^{210} data do not appear to increase significantly as the bottom is approached. The total depth at all three stations was between 250 and 265 meters. Figure 14 demonstrates clearly that, while the surface mixed layer, to about 80 meters, appears to show equilibrium activity ratios of Po^{210}/Pb^{210}, systematic disequilibria occur in the mid-water column. In the warm water core dissolved Po^{210} is at a twofold excess over dissolved Pb^{210} while the particulate Po^{210}/Pb^{210} ratios are systematically depleted in Po^{210}. In the cold water core the Po^{210}/Pb^{210} ratio in the particulates decreases slightly and then increases gradually to near equilibrium values in the bottom water. At station 2151 in the Murray Basin, which has somewhat colder and fresher bottom water than either station 2122 or 2138, in the Wilkinson Basin, the near bottom particulates are still depleted in Po^{210}. The dissolved Po^{210}/Pb^{210} ratios decrease slightly with depth as the bottom is approached but Po^{210} is still significantly in excess in the near bottom waters.

Table 4 presents data on the integrated concentrations over three depth ranges and for the total water column. The depth range from 0 to 80 m corresponds to the overturn depth of the cooling surface water. The range from 80 to 140 meters in the residual warm water core and from 140 to 260 meters represents the colder bottom waters. It is clear from these data that even when integrated over the whole water column an excess of Po^{210} is observed.

Figure 15 shows the total particulate matter profiles at each station. The mixed layer has low and relatively uniform concentrations of particles which decrease slightly into the top of the warm core layer, which has the clearest water. Particulate concentrations increase slightly through to the base of the warm core and the cold core layer has slight particle maxima at two of the stations. A pycnocline between the cold core and the warmer bottom water, occurring at about 220 meters marks the dramatic increase in particulate concentration in the near bottom waters. The specific activities of the Po^{210} and Pb^{210} are shown in Figures 16 and 17.

Discussion

The significant excesses of Po^{210} over Pb^{210} have been an unexpected but important finding. They confirm the subsurface excesses reported by us from the open ocean samples and indicate that the remineralization of particulate polonium in the immediate subsurface of the ocean is occurring at a relatively high rate (Bacon, 1975; Bacon et al., 1976).

The near equilibrium condition of both the dissolved and particulate ratios in the surface mixed layer is in marked contrast to our data from the north equatorial Atlantic Ocean where the surface layers are strongly depleted in dissolved polonium while the particulate matter has an excess. Further, the pronounced surface maximum in Pb^{210} that is a consistent feature of the open ocean stations is not well represented in the Gulf of Maine. Surface dissolved Pb^{210} concentrations of 15-20 dpm $100\ell^{-1}$ are common in the equatorial Atlantic which compares with 1.6 dpm $100\ell^{-1}$ in the Gulf of Maine samples.

Recently, Bacon (1975) and Benninger (1976) have shown that the flux of Pb^{210} into the surface waters of the ocean is dominated by an atmospheric input from the fallout and washout of Pb^{210} produced by decay of Rn^{222} introduced into the atmosphere from the continents. The flux of Pb^{210} to the surface has been estimated as about 0.6 dpm cm^{-2} yr^{-1} for the open ocean up to about 1.0 dpm cm^{-2} yr^{-1} for Long Island Sound. In our report of last year (Spencer, 1975) we discuss the calculation of the atmospheric Pb^{210} flux into Buzzards Bay sediment to be about 0.7 dpm cm^{-2} yr^{-1}.

These flux estimates, together with others, are sufficiently consistent that the atmospheric input of Pb^{210} into the Gulf of Maine is unlikely to be greatly different from 0.7 dpm cm^{-2} yr. When this figure is compared with the total integrated Pb^{210}, in the Murray-Wilkinson Basin water column, of 0.576 dpm cm^{-2}, it is clear that the residence time of Pb^{210} in the coastal waters is short.

Benninger (1976) has demonstrated that other fluxes (from rivers, open ocean exchange, ground water and in situ radium support) make minor contributions to the flux of Pb^{210} into Long Island Sound. It is unlikely that the situation is different in the Gulf of Maine. A conspicuous feature of the Murray-Wilkinson Basin is the standing nepheloid layer which we have observed now to be a quasi-permanent phenomenon (Spencer and Sachs, 1970). This layer, which probably represents bottom sediments resuspended by tidal currents contributes "Po^{210}-old" particulate matter to the water column as is evident from the tendency of the Po^{210}/Pb^{210}

ratios in the suspended matter to approach equilibrium in the near bottom. If the specific activity of this recently resuspended material is about 20 dpm gm^{-1} then it could contribute a maximum of 0.064 dpm cm^{-2} to the standing crop of Pb^{210} in the water column and the total due principally to the atmospheric flux would be about 0.512 dpm cm^{-2}. At an input rate 0.71 dpm cm^{-2} yr^{-1} the residence time of Pb^{210} in the Murray-Wilkinson Basin waters is only 0.72 yr, which compares with calculated values of about 2.5 yrs for the residence time of Pb^{210} in open ocean waters.

This, together with the integrated excess polonium, strongly suggests that the water column is not at a steady state with regard to these isotopes and it is highly likely that significant seasonal variations in the abundance and distribution of both Pb^{210} and Po^{210} in the water column will be observed.

The data from the Gulf of Maine show many similarities to those from Long Island Sound, as determined by Benninger (1976). Although direct measurement of the particulate Pb^{210}, Po^{210} concentrations was not made in Long Island Sound, Benninger uses the slope of regressions of total Pb^{210} and Po^{210} on total suspended matter to suggest specific activities of 12-30 dpm gm^{-1} for Pb^{210} and Po^{210} and intercept values of 0-0.012 dpm kg^{-1} to indicate low concentrations of "dissolved" isotopes quite comparable to our measurements given in Table 1.

The major difference between Long Island Sound and the Gulf of Maine is the quantity of suspended material which dominates the water column distribution of Pb^{210} and Po^{210} in Long Island Sound but form variously

about 50% of the isotopes in the Gulf of Maine. This is certainly due to the shallower more highly energetic bottom conditions prevalent in Long Island Sound and the greater occurrence of resuspended sediment loads. Although it is highly likely that non-steady state conditions exist in the isotope distributions and, as we surmised in our proposal, seasonal studies will be necessary to determine the temporal variations, it is useful to speculate upon the nature of these temporal variations and the extent to which the January conditions, as recorded by us, could have arisen.

The spring plankton bloom in the Gulf of Maine occurs in April-May with the establishment of a summer thermocline at about 50 m. Ketchum (1968) has demonstrated that significant but reduced productivity continues throughout the summer and then declines in October-November after a fall bloom that accompanies the first winter storms. Bacon et al. (1976) have shown that Po^{210} is markedly enriched in surface suspended matter under steady productivity conditions and Turekian (personal communication) has observed pronounced enrichments of Po^{210} in zooplankton. The data of Table 3 indicate that the 158μ seston component has Po^{210}/Pb^{210} activity ratios of 6.5-8.6.

It appears possible that during the summer months the surface could be strongly depleted in dissolved Po^{210}. It is not unlikely that the excess dissolved Po^{210} observed in the deep water is the result of the remineralization of particulate Po^{210} grown during the summer season.

We might consider a simple model for the regeneration of dissolved from particulate polonium in the whole basin as

$$\frac{dPo^D}{dt} = -\lambda Po^D + \lambda Pb^D + J \qquad 1$$

and

$$\frac{dPo^P}{dt} = -\lambda Po^P - Po^P S - J + \lambda Pb^P \qquad 2$$

where

Po^D = activity Po^{210} dissolved

Po^P = activity Po^{210} particulate

λ = decay constant Po^{210} = 1.833 yr^{-1}

Pb^D = activity Pb^{210} dissolved

Pb^P = activity Pb^{210} particulate

S = settling velocity

J = production rate of dissolved from particulate Po^{210}

Solutions to these equations are given by

$$Po^D = C_1 e^{-\lambda t} + \frac{J + Pb^D}{\lambda} \qquad 3$$

$$Po^P = C_2 e^{-(\lambda+S)t} + \frac{\lambda Pb^P - J}{(\lambda+S)} \qquad 4$$

If we consider the time from the January date of the collection of our samples to the last major input of organic particles to be 4.5 to 6 months and, further, if we assume that the Po^D/Pb^D ratio initially varied between 0.1 and 1 we may use these boundary conditions and equation 3 to calculate values of J and the constant C_1 and then calculate the intial

Po^P required to satisfy the conditions. If such a value of Po^P is unreasonable then the model must be clearly in error. For example, if we assume the regeneration period t to be six months (0.5 yr) and if we assume that, initially, at t = o, $Po^D = Pb^D$ then from equation 3 and Table 4 we get, assuming the integrated Pb^{210} to change slowly

$$.308 = C_1 + \frac{J}{\lambda} + .308 \qquad 5$$

At t = 0.5, the measured conditions, equation 3 and Table 4 give

$$0.422 = C_1 \ .401 + \frac{J}{\lambda} + .308 \qquad 6$$

Solving 5 and 6 simultaneously we get J = 0.35 dpm cm^{-2} yr^{-1} (or 0.013 dpm kg^{-1} yr^{-1}).

In order to proceed further and use equation 4 we need to estimate the settling velocity S. One method is to use the residence time of Pb^{210}, calculated earlier at 0.72 yr to estimate a particle settling velocity of 260 m/.72 yr or 350 m yr^{-1} which seems in reasonable agreement with the velocities predicted by others for fine particles in the ocean.

If we assume that Po and Pb are transported at similar velocities we can use the same boundary conditions at t = .5 and equation 4 to solve for C_2 and then calculate Po^P the initial particulate polonium concentration. Table 5 illustrates the results of such calculations.

The range of values calculated for the initial particulate Po^{210} concentrations are somewhat in excess of those measured during our collections in January, but they are quite comparable with the determinations of Benninger (1975) in Long Island Sound, where Po^{210} concentrations,

principally particulate, range from .041 dpm kg^{-1} to 0.218 dpm kg^{-1}. Further, the range of J from 0.013 to 0.036 dpm kg^{-1} yr^{-1} compares with the similar rate of 0.038 dpm kg^{-1} yr^{-1} determined by Bacon (1975) for the remineralization of Po^{210} in the 100 to 300 meter depth zone of the north equatorial Atlantic.

Further work is necessary to validate and extend these calculations. In the proposal for the coming year we are proposing a summer cruise to the Gulf of Maine in order to supply the summer contrast with our present data. Also, we propose to set a series of sediment traps to obtain direct measurements of some of the particulate fluxes.

Table 1. Lead-210 and Polonium-210 in the Gulf of Maine. Cruise Atlantis II #86, January, 1975.

Station	Depth (m)	Temp (°C)	Salinity ‰	Oxygen (mℓ ℓ$^{-1}$)	Silicate (μM ℓ$^{-1}$)	Lead-210 (dpm 100ℓ$^{-1}$) Total	Lead-210 (dpm 100ℓ$^{-1}$) Part	Polonium-210 (dpm 100ℓ$^{-1}$) Total	Polonium-210 (dpm 100ℓ$^{-1}$) Part	Total Particulate (μg kg^{-1})	Particulate dpm gm^{-1} Pb^{210}	Particulate dpm gm^{-1} Po^{210}
2122	0		33.361	6.25	9.0	2.60±.20	1.05±.06	2.52±.32	1.04±.09	88	119	118
	39	7.50	33.378	6.17	9.0	2.65±.20	1.24±.09	2.88±.38	1.29±.12	90	138	143
	80	7.69	33.455	6.17	9.0	2.93±.17	1.09±.06	3.07±.30	1.08±.08	100	109	108
	117	7.71	33.451	6.16	9.0	2.92±.17	1.32±.06	3.38±.29	1.09±.12	90	147	121
	150	7.89	33.509	5.02	9.5	2.04±.21	1.37±.06	2.61±.30	0.68±.17	106	129	64
	175	6.96	33.792	4.72	15.5	1.38±.26	0.49±.09	1.93±.34	0.31±.22	100	49	31
	191	6.95		4.65		1.44±.23	0.89±.05	1.39±.41	0.61±.11	150	59	41
	220		34.064	4.20	17.5	2.79±.23		1.94±.47		190		
	248	7.36	34.187	4.00	19.0	2.53±.21	1.03±.08	2.83±.38	1.00±.16	325	32	31
2138	10	7.13	33.237	6.59	8.8	2.94±.20	1.32±.04	2.72±.35	1.10±.07	75	176	147
	93	7.76	33.511	6.17	8.6	2.43±.19	1.05±.08	2.68±.33	0.95±.14	41	256	232
	181	7.05	33.980	4.43	15.8	1.39±.28	0.84±.08	2.04±.25	0.54±.17	83	101	65
	210	7.10	34.114	4.34	17.8	1.57±.24	0.78±.08	1.72±.43	0.63±.17	144	54	44
	238	7.29	34.187	4.12	18.4	1.55±.24	0.83±.09	2.19±.37	0.83±.15	310	27	27
	259	7.36	34.184	4.07	18.6	1.80±.23	0.95±.08	2.07±.33	0.85±.19	460	21	18
	10*					1.76±.28		1.69±.46				
	93*					1.57±.29		1.96±.41				
2151	10		33.390	6.44	8.6	2.95±.23	1.02±.09	3.03±.38	1.21±.11	58	175	208
	37	7.47	33.309	6.45	8.8	2.68±.19	1.13±.09	2.50±.31	1.14±.11	70	161	163
	65	7.46	33.396	6.49	10.1	4.48±.21	1.09±.10	5.45±.32	1.01±.14	62	176	163
	95	7.54	33.471	6.40	9.1	2.64±.17	1.13±.09	2.70±.35	1.21±.12	60	188	202
	123	7.74	33.557	6.28	9.2	2.40±.18	1.19±.09	2.77±.31	0.65±.18	66	180	98
	154	7.45	33.659	4.93	14.6	2.02±.18	1.34±.07	2.69±.32	1.08±.13	110	121	98
	181	7.29	33.859	4.72	15.2	1.49±.22	0.91±.06	2.43±.37	0.81±.09	245	37	33
	208	7.09	34.020	4.51	17.0	1.26±.25	0.77±.07	1.78±.38	0.38±.24	244	32	16
	240		34.131	4.30	19.5	1.63±.21	0.86±.09	2.08±.34	0.42±.21	390	22	11

*Filtered Sample

Table 2. Lead-210 and Polonium-210 in the Gulf of Maine. Cruise Atlantis II #86, January, 1975.

Station	Depth (m)	Dissolved Pb^{210} dpm $100\ell^{-1}$	Particulate Pb^{210} cpm $100\ell^{-1}$	Dissolved Po^{210} dpm $100\ell^{-1}$	Particulate Po^{210} dpm $100\ell^{-1}$	Dissolved Po^{210}-Pb^{210} dpm $100\ell^{-1}$	Particulate Po^{210}-Pb^{210} dpm $100\ell^{-1}$	Activity ratio Po^{210}/Pb^{210} Dissolved	Activity ratio Po^{210}/Pb^{210} Particulate
2122	0	1.55±.20	1.05±.06	1.48±.32	1.04±.09	-.07±.32	-.01±.09	0.95±.27	0.99±.08
	39		1.24±.09		1.29±.12		-.05±.12		1.04±.11
	80	1.84±.17	1.09±.06	1.99±.30	1.08±.08	0.15±.30	-.01±.08	1.08±.24	0.99±.07
	117	1.60±.17	1.32±.06	2.29±.29	1.09±.12	0.69±.29	-.23±.12	1.43±.24	0.83±.09
	150	0.67±.21	1.37±.06	1.93±.30	0.68±.17	1.26±.30	-.69±.17	2.88±.26	0.50±.13
	175	0.89±.26	0.49±.09	1.62±.34	0.31±.22	0.73±.34	-.18±.22	1.82±.24	0.63±.17
	191		0.89±.05		0.61±.11		-.28±.11		0.69±.09
	220								
	248		1.03±.08		1.00±.16		-.03±.16		0.97±.13
2138	10	1.62±.20	1.32±.04	1.62±.35	1.10±.07	0.00±.35	-.22±.07	1.00±.29	0.83±.06
	93	1.38±.19	1.05±.08	1.73±.33	0.95±.14	0.35±.33	-.10±.14	1.25±.27	0.90±.11
	181	0.55±.28	0.84±.08	1.50±.25	0.54±.17	0.95±.28	-.30±.17	2.73±.27	0.64±.13
	210	0.79±.24	0.78±.08	1.09±.43	0.63±.17	0.30±.43	-.15±.17	1.38±.35	0.81±.13
	238	0.72±.24	0.83±.09	1.36±.37	0.83±.15	0.74±.37	0.00±.15	1.89±.31	1.00±.12
	259	0.85±.23	0.95±.08	1.22±.33	0.85±.19	0.37±.33	-.10±.19	1.44±.28	0.89±.15
	10*	1.76±.28		1.69±.46		-.07±.46			
	93*	1.57±.29		1.96±.41		0.39±.41			
2151	10	1.93±.23	1.02±.09	1.82±.38	1.21±.11	-.11±.38	0.19±.11	0.94±.31	1.19±.10
	37	1.55±.19	1.13±.09	1.36±.31	1.14±.11	-.19±.31	0.01±.11	0.88±.26	1.01±.10
	65	3.39±.21	1.09±.10	4.44±.32	1.01±.14	1.05±.32	-.08±.14	1.31±.27	0.93±.12
	95	1.51±.17	1.13±.09	1.49±.35	1.21±.12	-.02±.35	0.08±.12	0.99±.28	1.07±.11
	123	1.21±.18	1.19±.09	2.12±.31	0.65±.18	0.91±.31	-.54±.18	1.75±.26	0.55±.14
	154	0.68±.18	1.34±.07	1.61±.32	1.08±.13	0.93±.32	-.26±.13	2.37±.26	0.81±.10
	181	0.58±.22	0.91±.06	1.62±.37	0.81±.09	1.04±.37	-.10±.09	2.79±.30	0.89±.08
	208	0.49±.25	0.77±.07	1.40±.38	0.38±.24	0.91±.38	-.39±.24	2.86±.32	0.49±.18
	240	0.77±.21	0.86±.09	1.66±.34	0.42±.21	0.89±.34	-.44±.21	2.16±.28	0.49±.16

* Filtered Sample

Table 3. Plankton tow data.

Station	Pb^{210} dpm g^{-1} wet wt	Pb^{210} dpm g^{-1} dry wt	Po^{210} dpm g^{-1} wet wt	Po^{210} dpm g^{-1} dry wt	Activity ratio Po^{210}/Pb^{210}
2122 (Total)	0.664±.01	4.89±.02	5.70±.01	41.98±.01	8.58
2128 (Fluid)					18.94
2128 (Solid)					5.15
2128 (Total)	0.183±.01	2.25±.02	1.36±.01	16.67±.01	7.40
2135 (Total)	0.408±.01	4.18±.003	2.60±.01	27.05±.01	6.48

Table 4. Integrated Pb^{210} and Po^{210} concentrations (dpm cm^{-2}).

Depth range (m)	Pb^{210} diss	Pb^{210} part	Po^{210} diss	Po^{210} part
0-80	0.128	0.088	0.128	0.088
80-140	0.096	0.078	0.126	0.054
140-260	0.084	0.102	0.168	0.084
Total	0.308	0.268	0.422	0.226
Total (particulate and dissolved)	0.576		0.648	

Table 5. Model calculations.

	Time t, yr	
Initial Po^D/Pb^D	0.375	0.5
1	J = 0.016 Po^P = 0.026	J = .013 Po^P = 0.036
0.1	J = 0.036 Po^P = 0.041	J = 0.024 Po^P = 0.048

Unit J = dpm kg^{-1} yr^{-1}

Po^P = dpm kg^{-1}

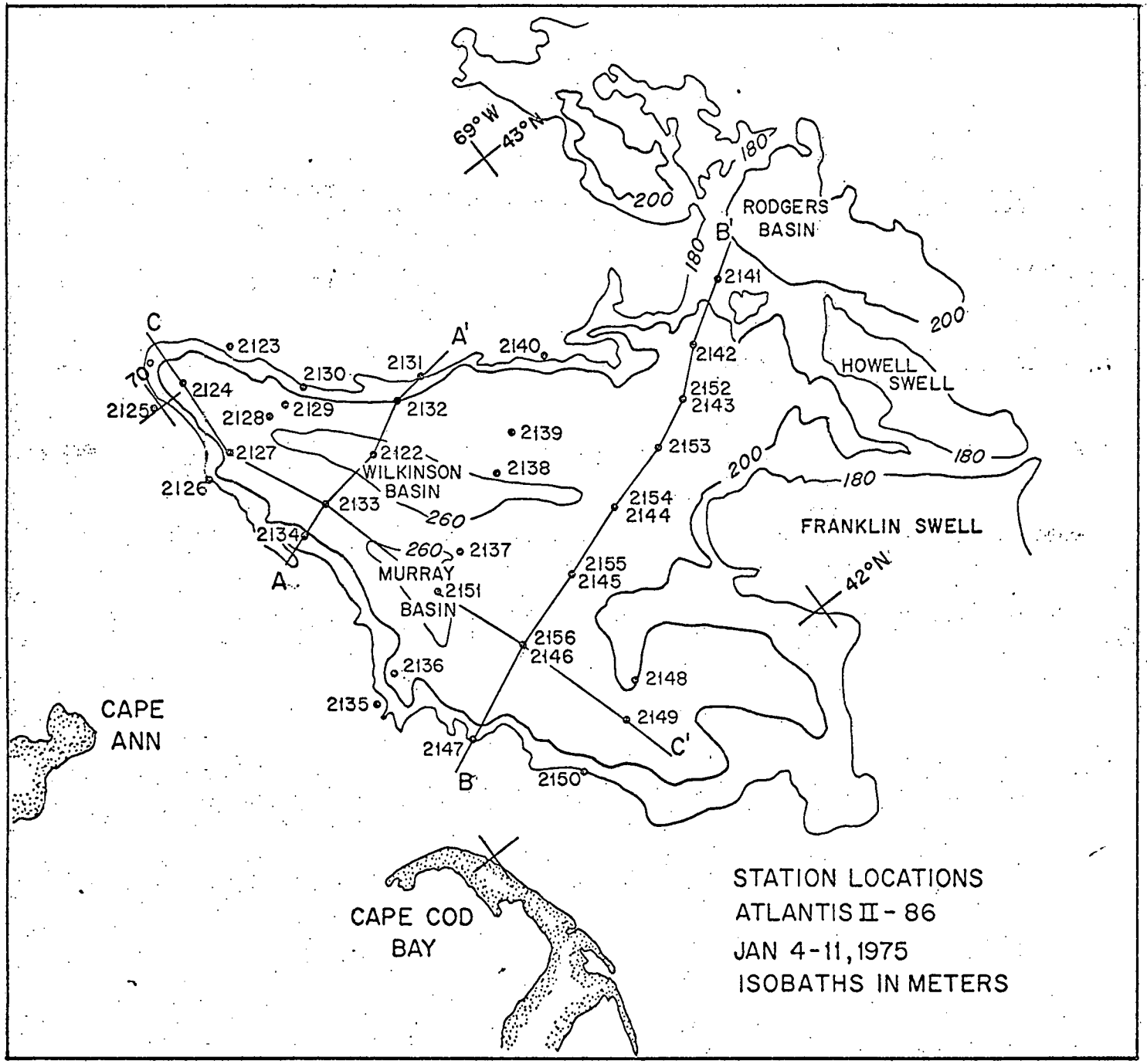


Figure 1. Station Locations

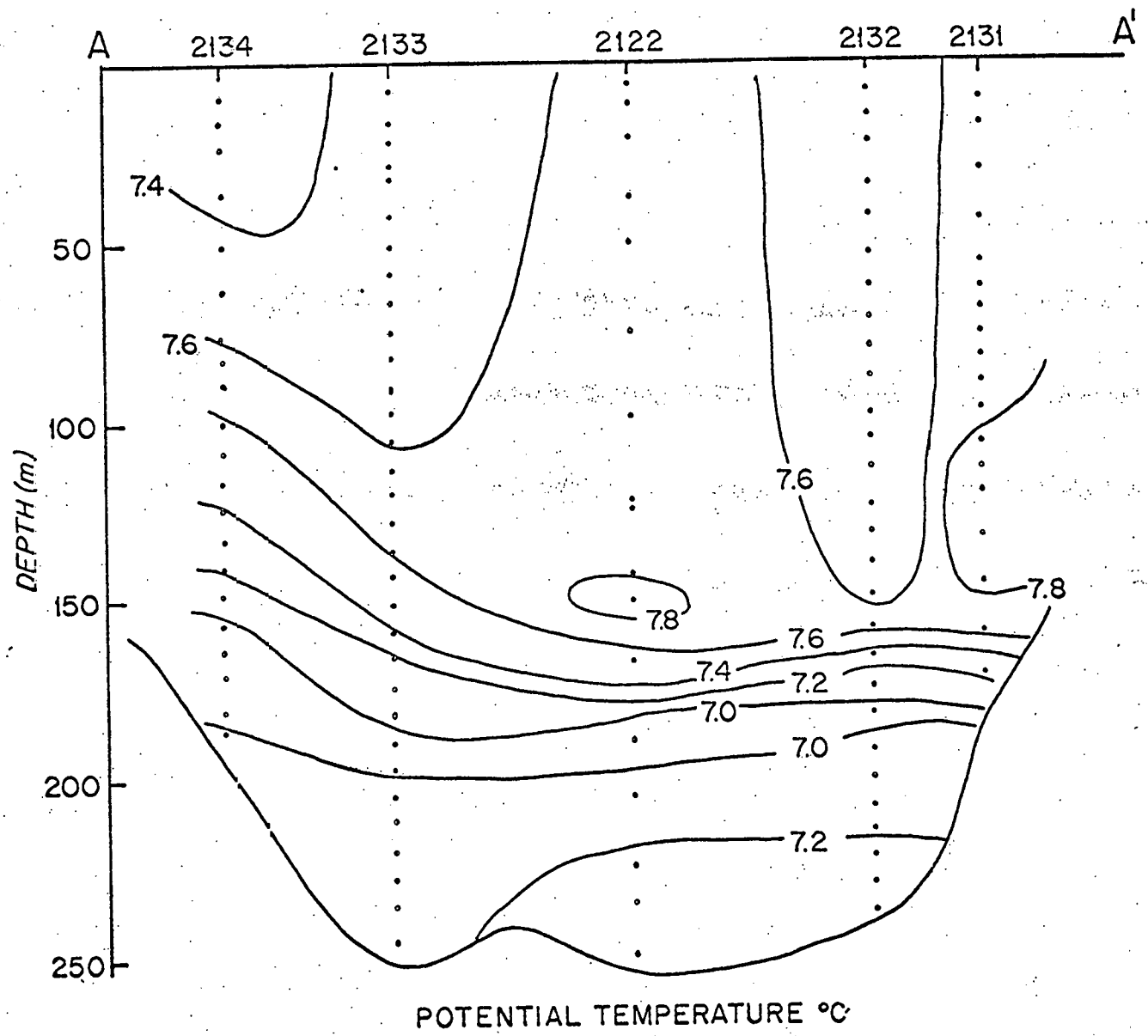


Figure 2. Potential temperature vs. depth for section A-A'

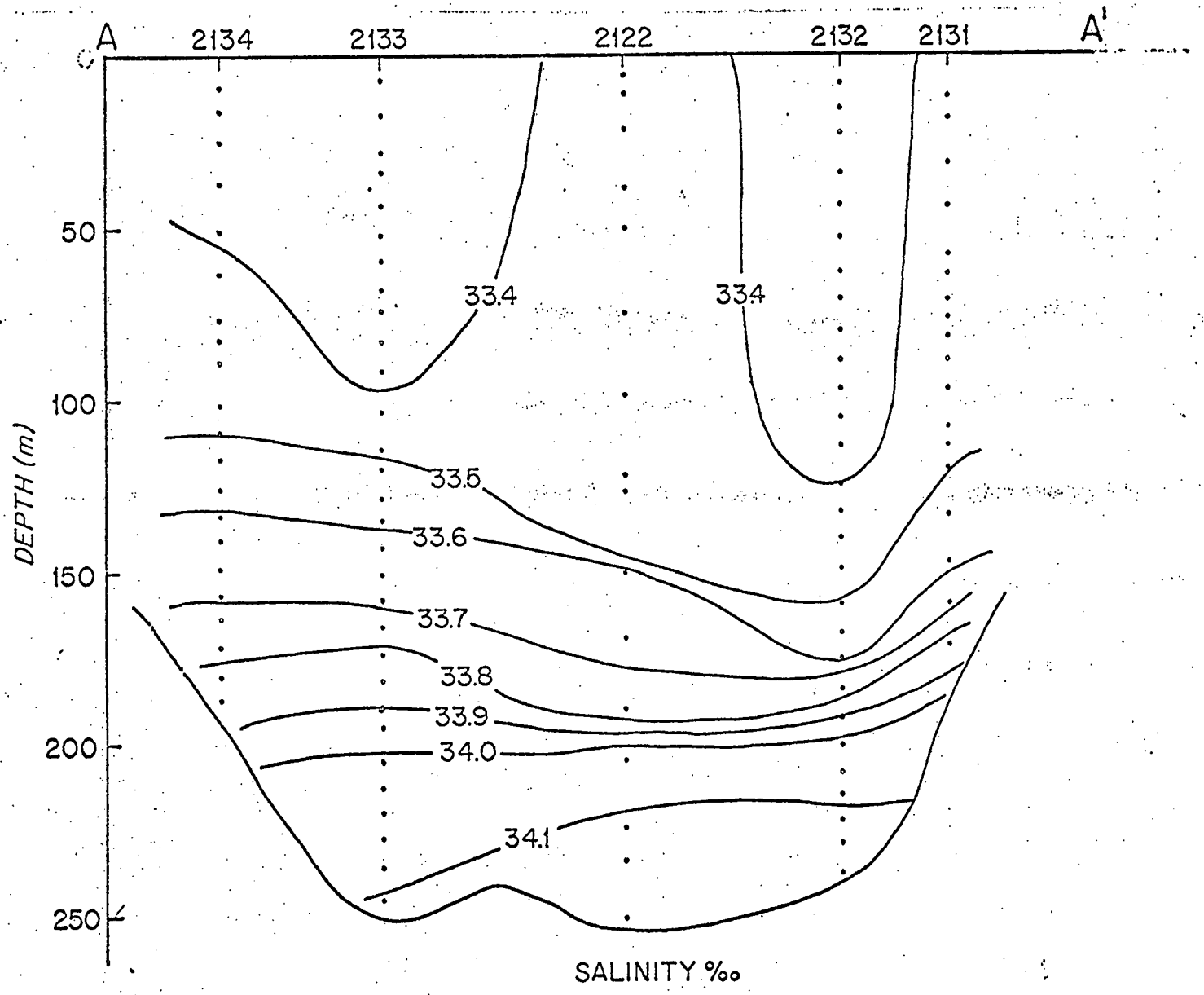


Figure 3. Salinity vs. depth for section A-A'

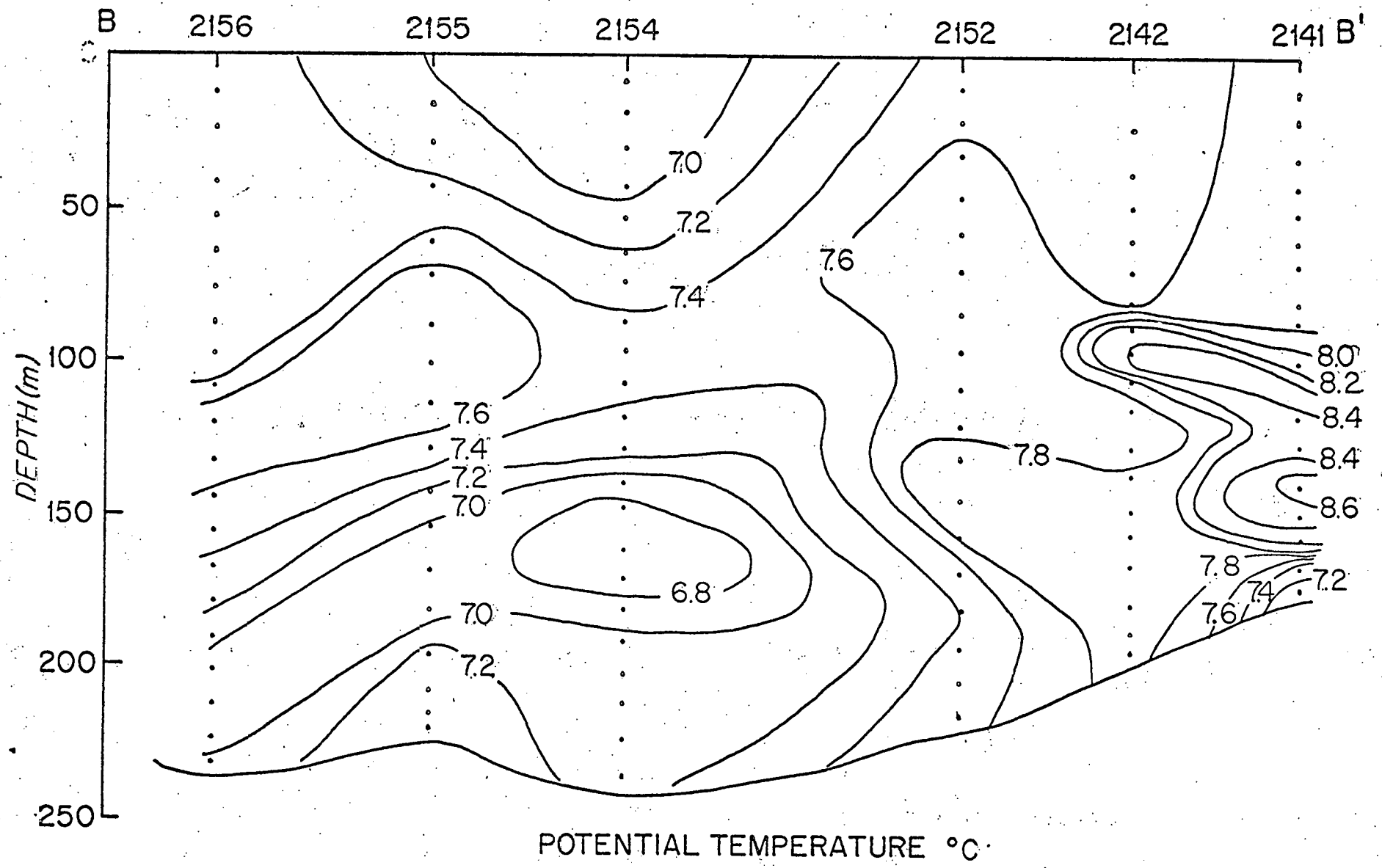


Figure 4. Potential temperature vs. depth for section B-B'

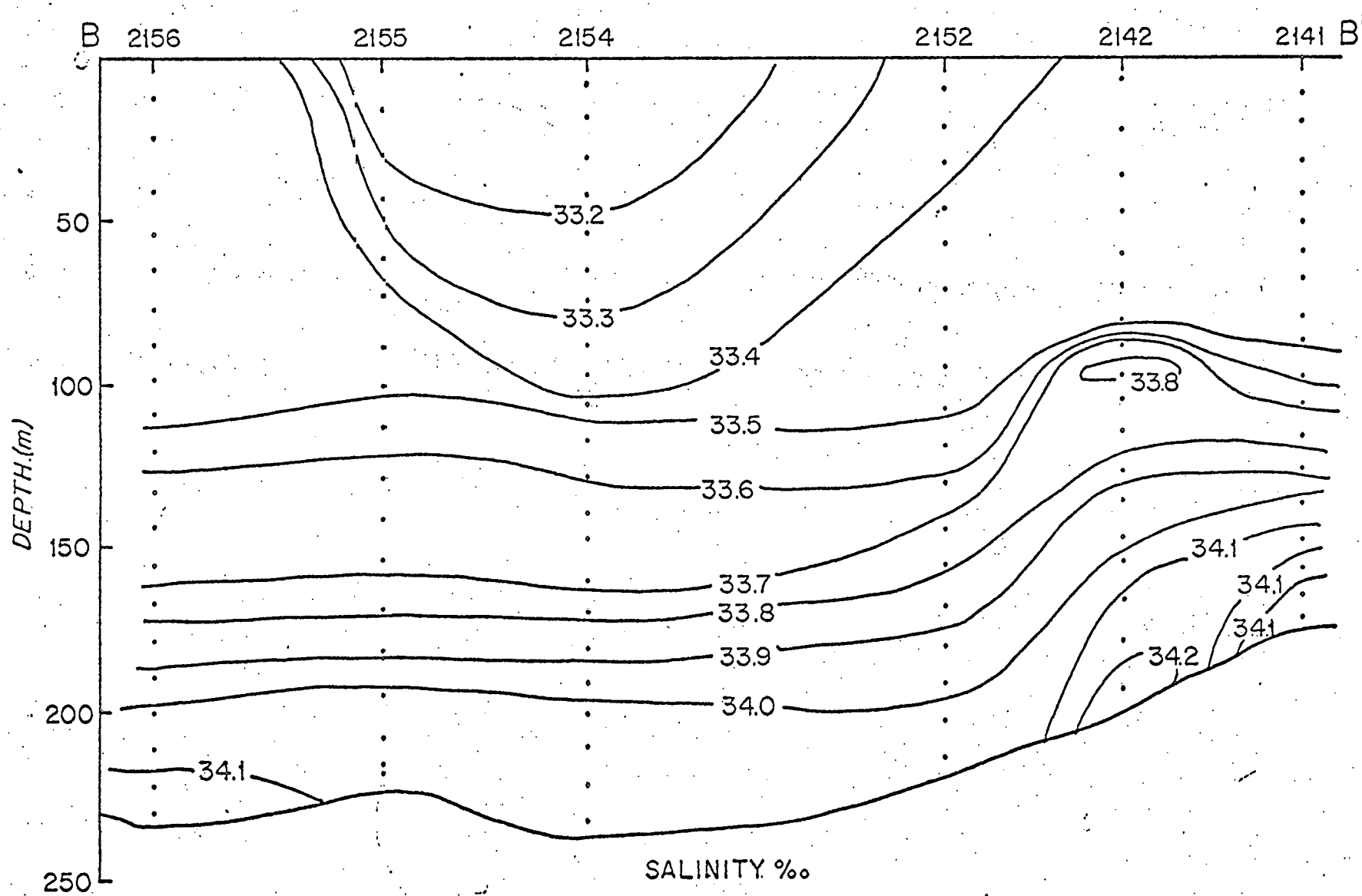


Figure 5. Salinity vs. depth for section B-B'

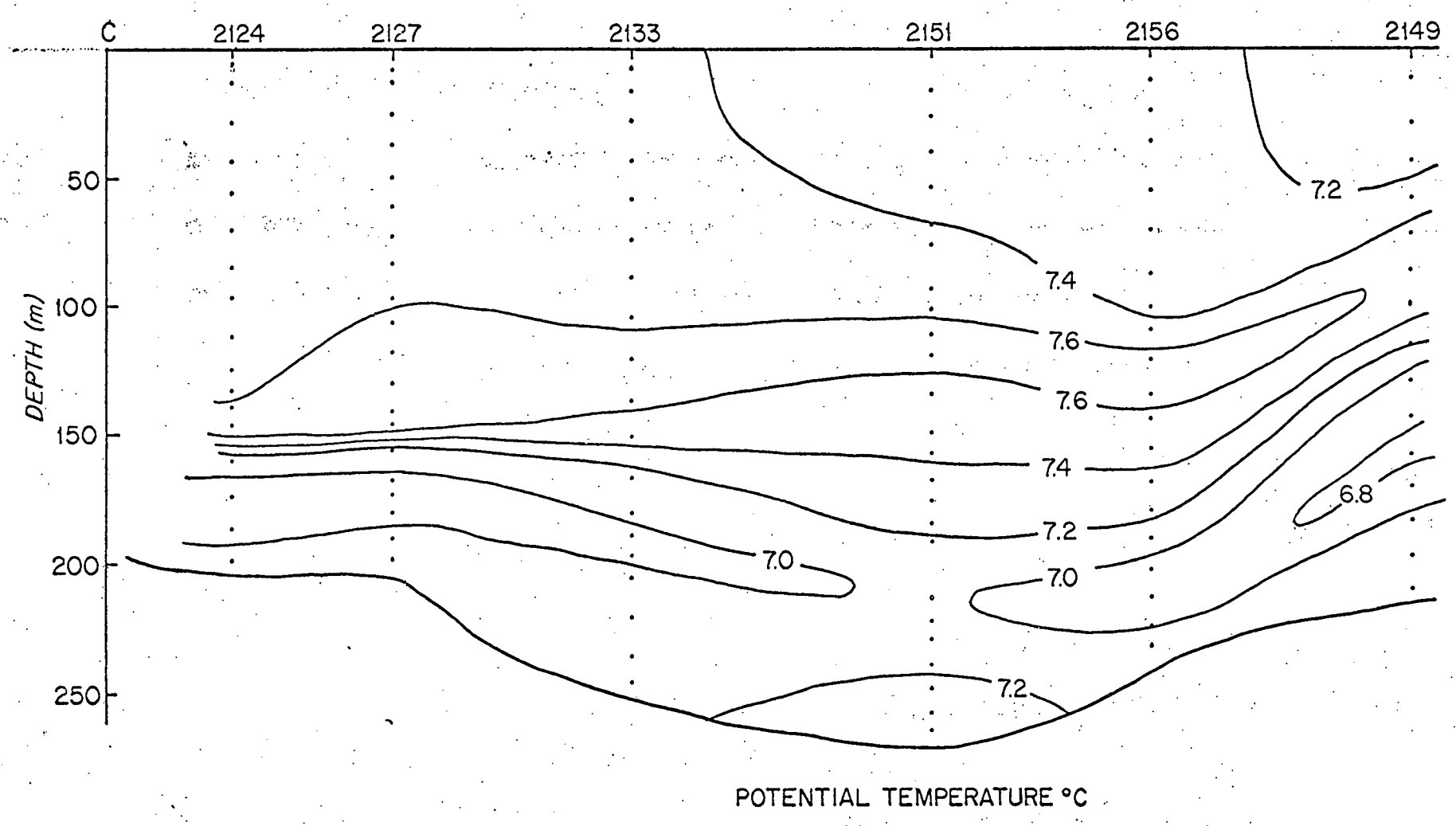


Figure 6. Potential temperature vs. depth for section C-C'

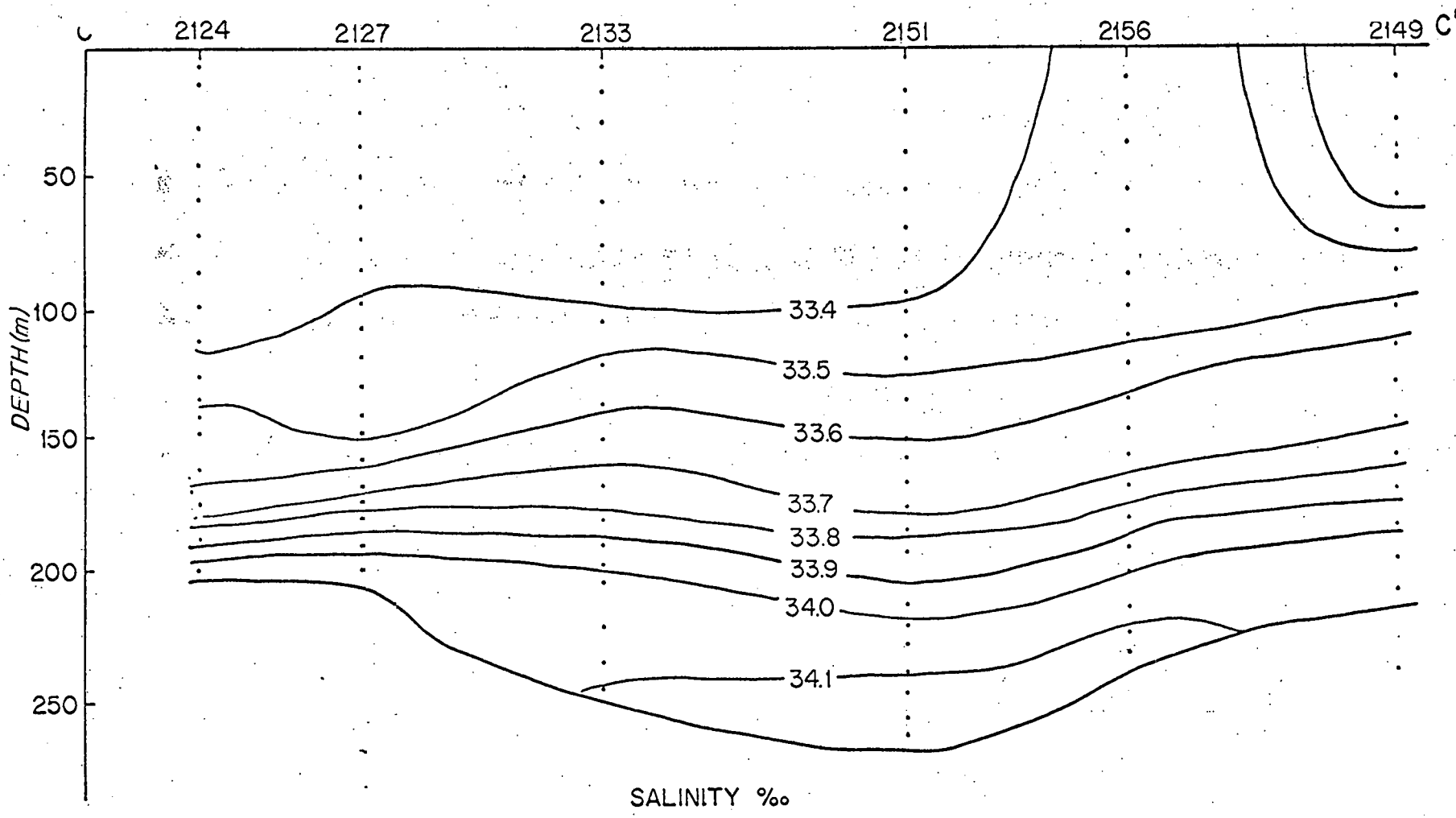


Figure 7. Salinity vs. depth for section C-C'

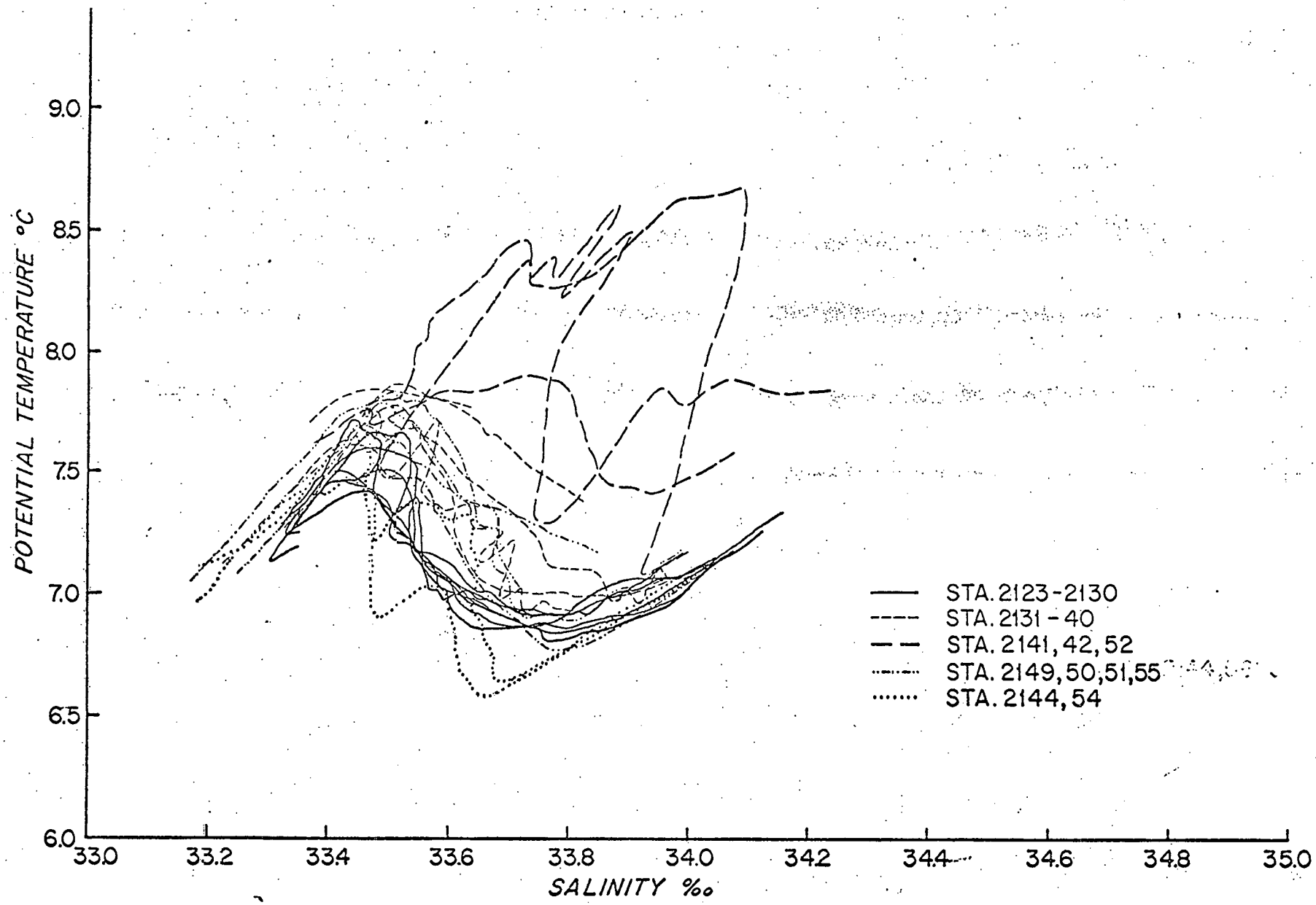


Figure 8. Composite plot of potential temperature vs. salinity

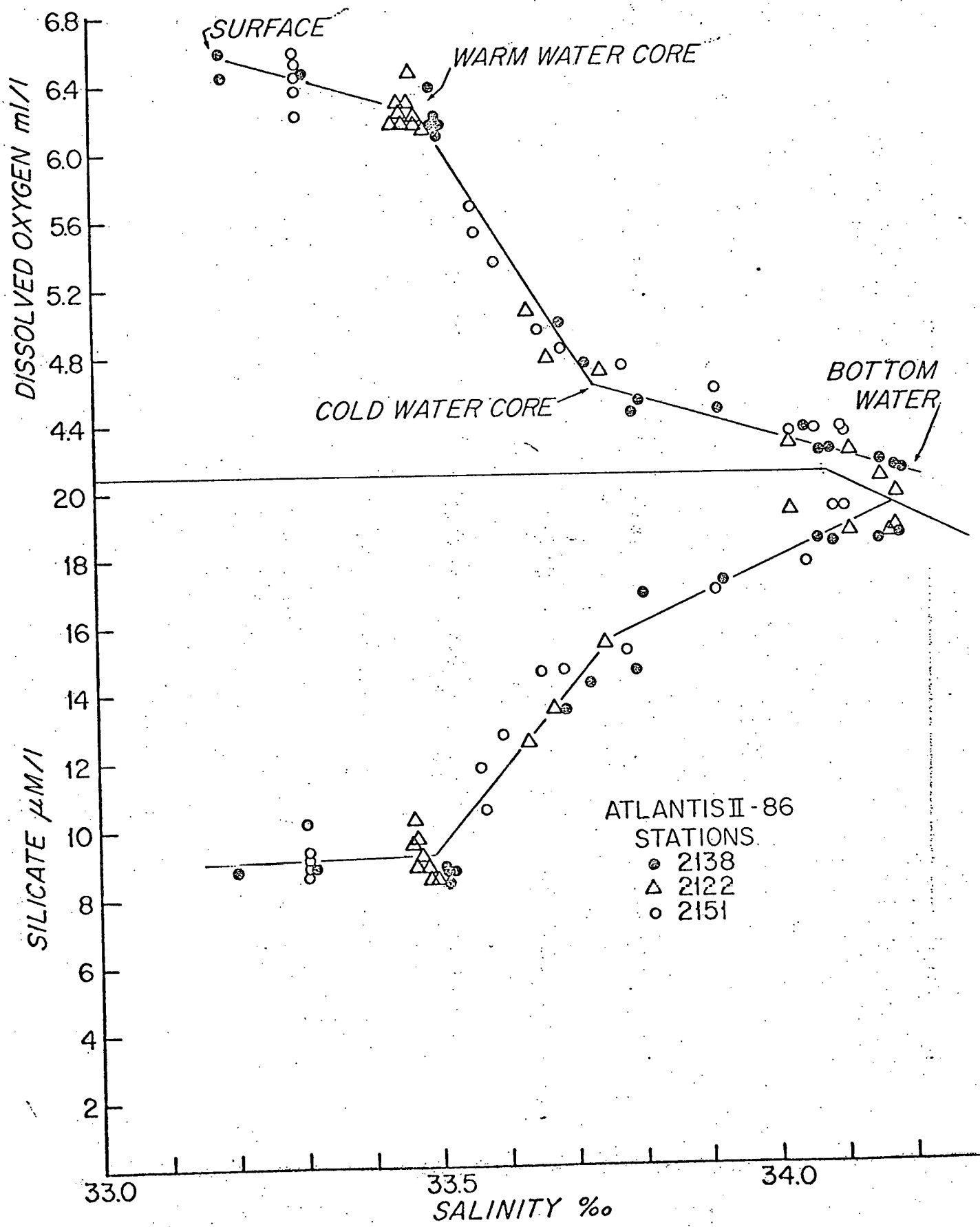


Figure 9. Salinity vs. dissolved oxygen and silicate

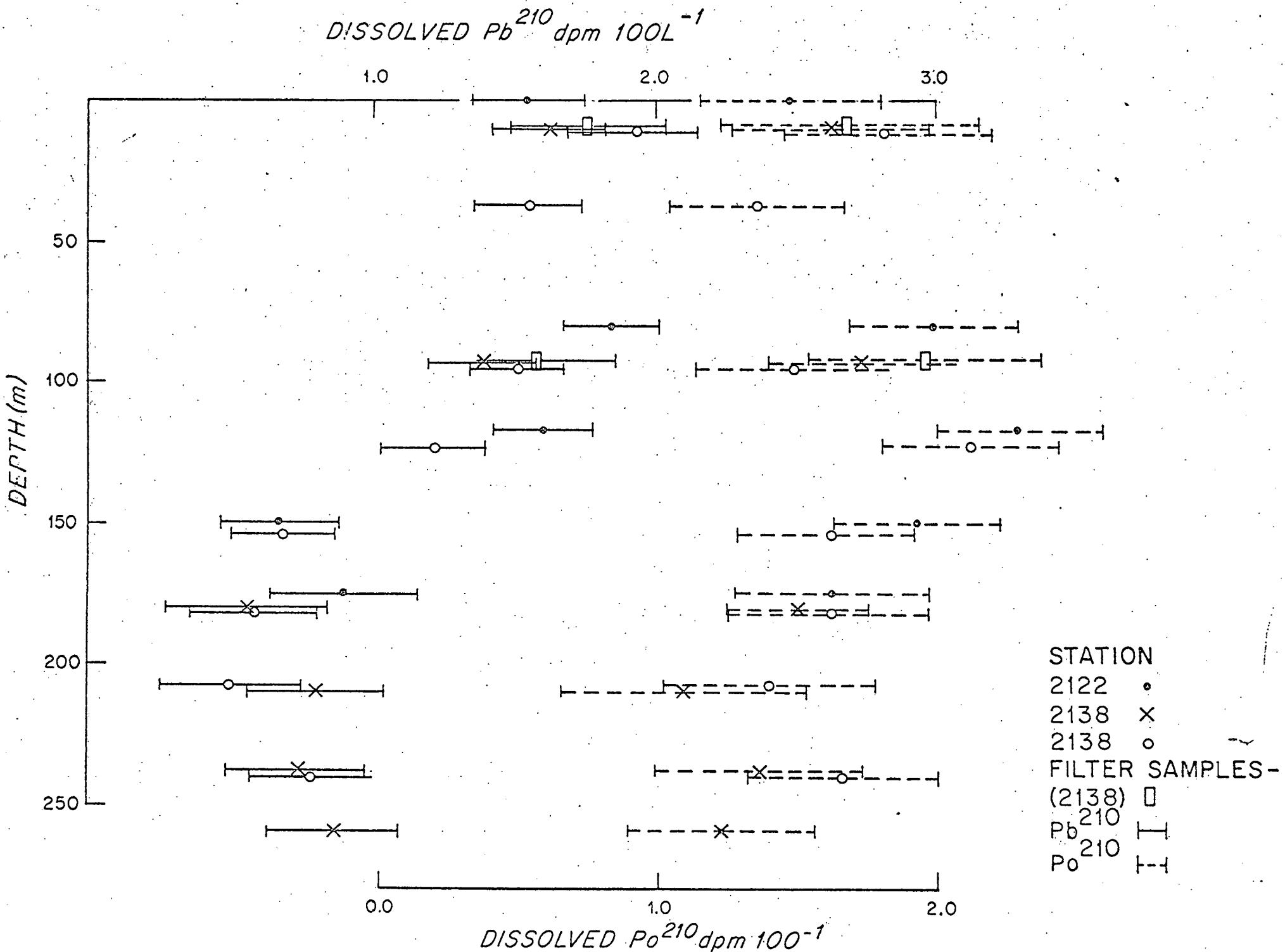

DISSOLVED Pb^{210} dpm $100L^{-1}$
1.0
2.0
3.0
50
100
150
200
250
DEPTH (m)
STATION
2122 o
2138 ×
2138 o
FILTER SAMPLES-
(2138) □
Pb^{210} ⊢
Po^{210} ⊢-⊣
0.0
1.0
2.0
DISSOLVED Po^{210} dpm 100^{-1}

Figure 10

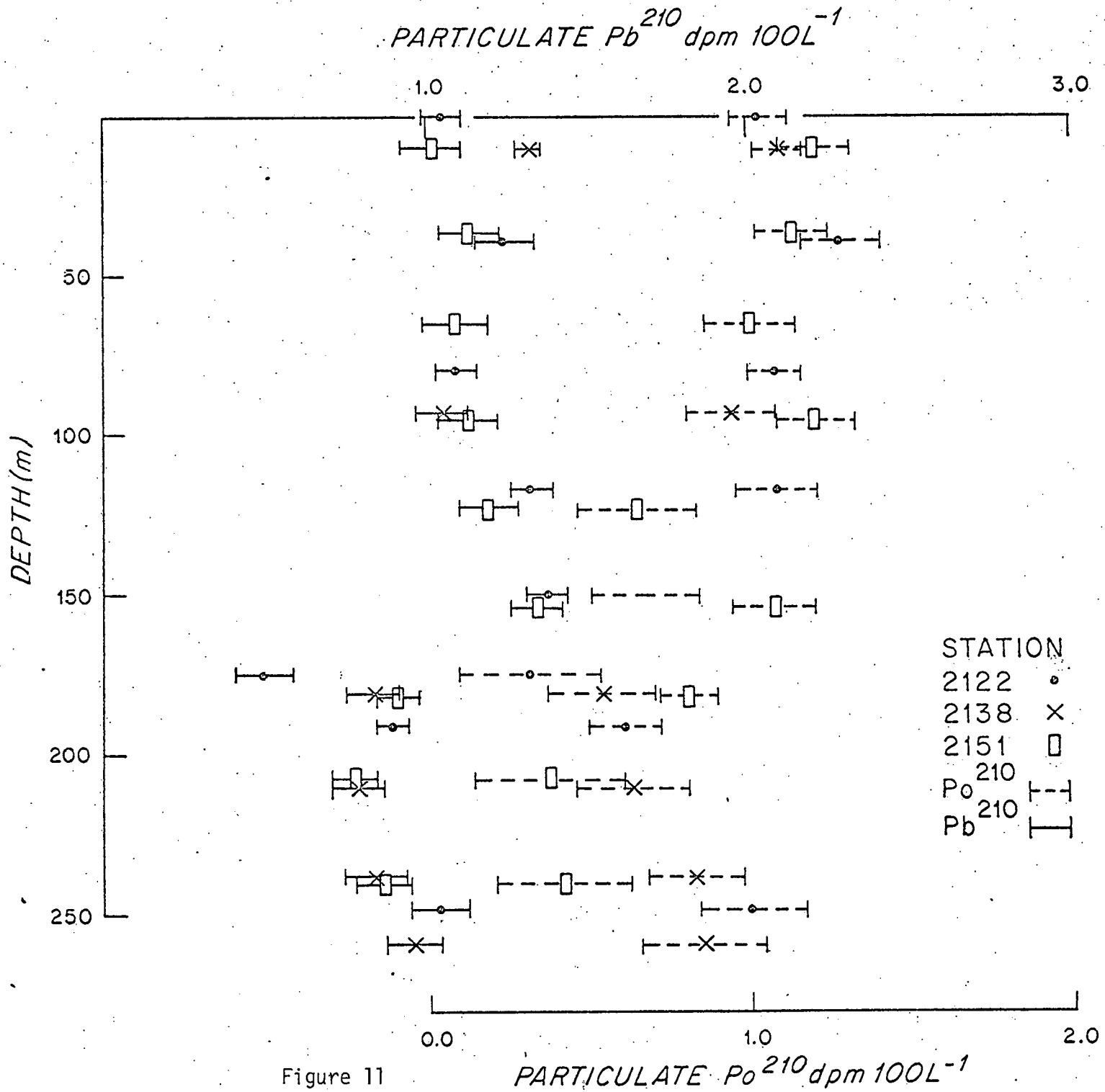

PARTICULATE Pb210 dpm 100L-1
1.0
2.0
3.0
DEPTH (m)
50
100
150
200
250
STATION
2122
2138
2151
Po210
Pb210
0.0
1.0
2.0
PARTICULATE Po210 dpm 100L-1

Figure 11

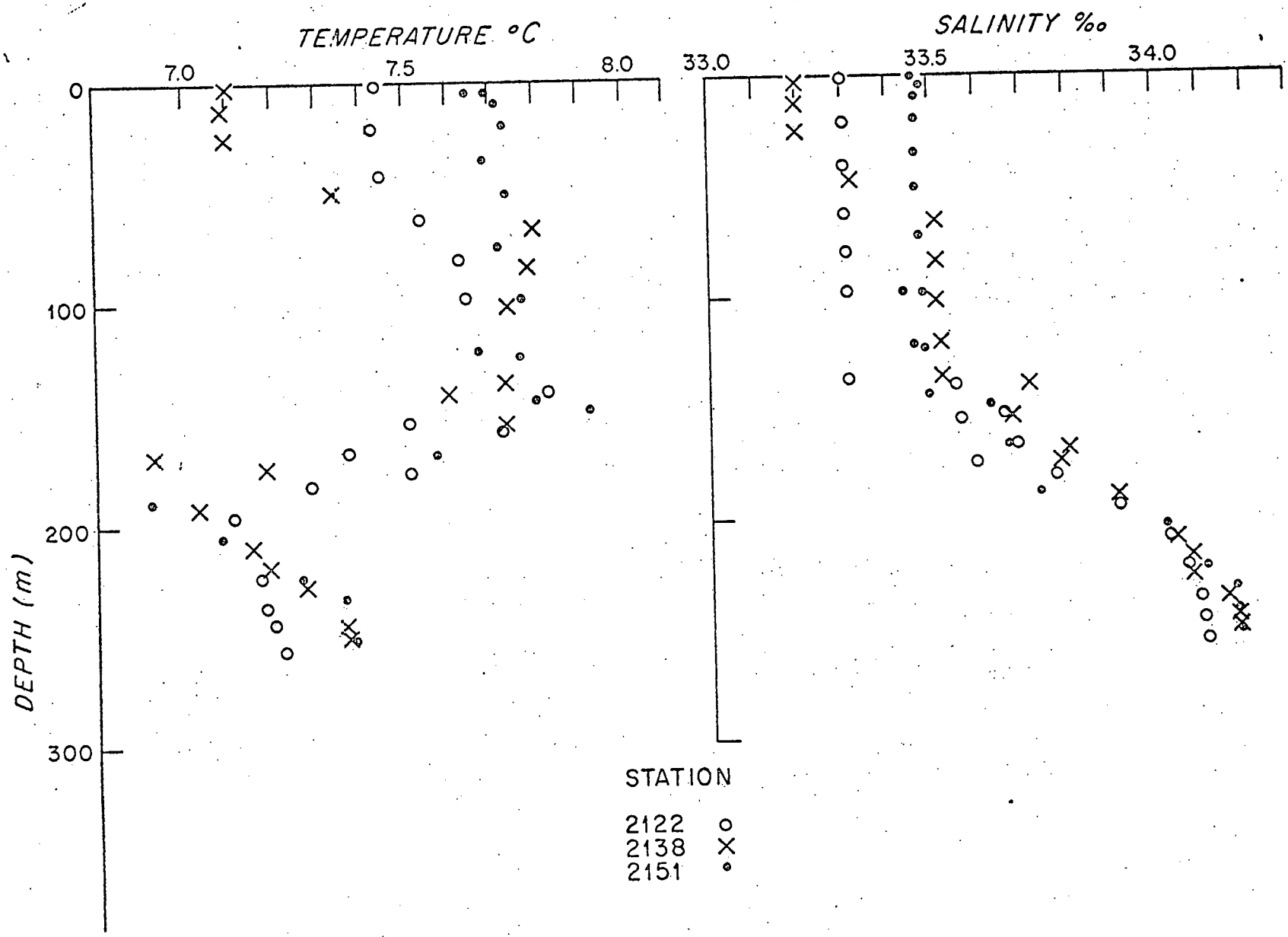

TEMPERATURE °C
7.0
7.5
8.0
SALINITY ‰
33.0
33.5
34.0
0
100
200
300
DEPTH (m)
STATION
2122
2138
2151

Figure 12

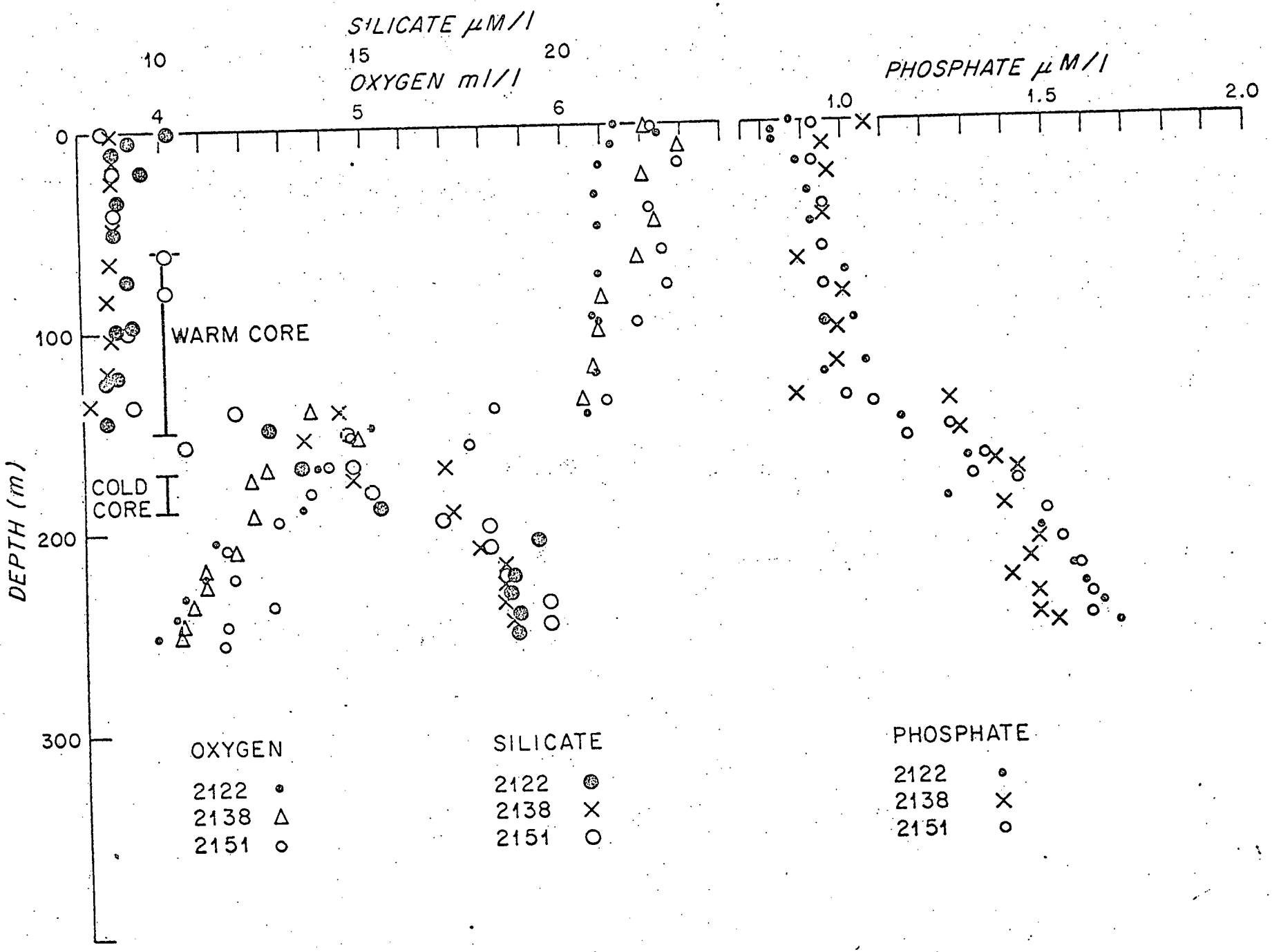
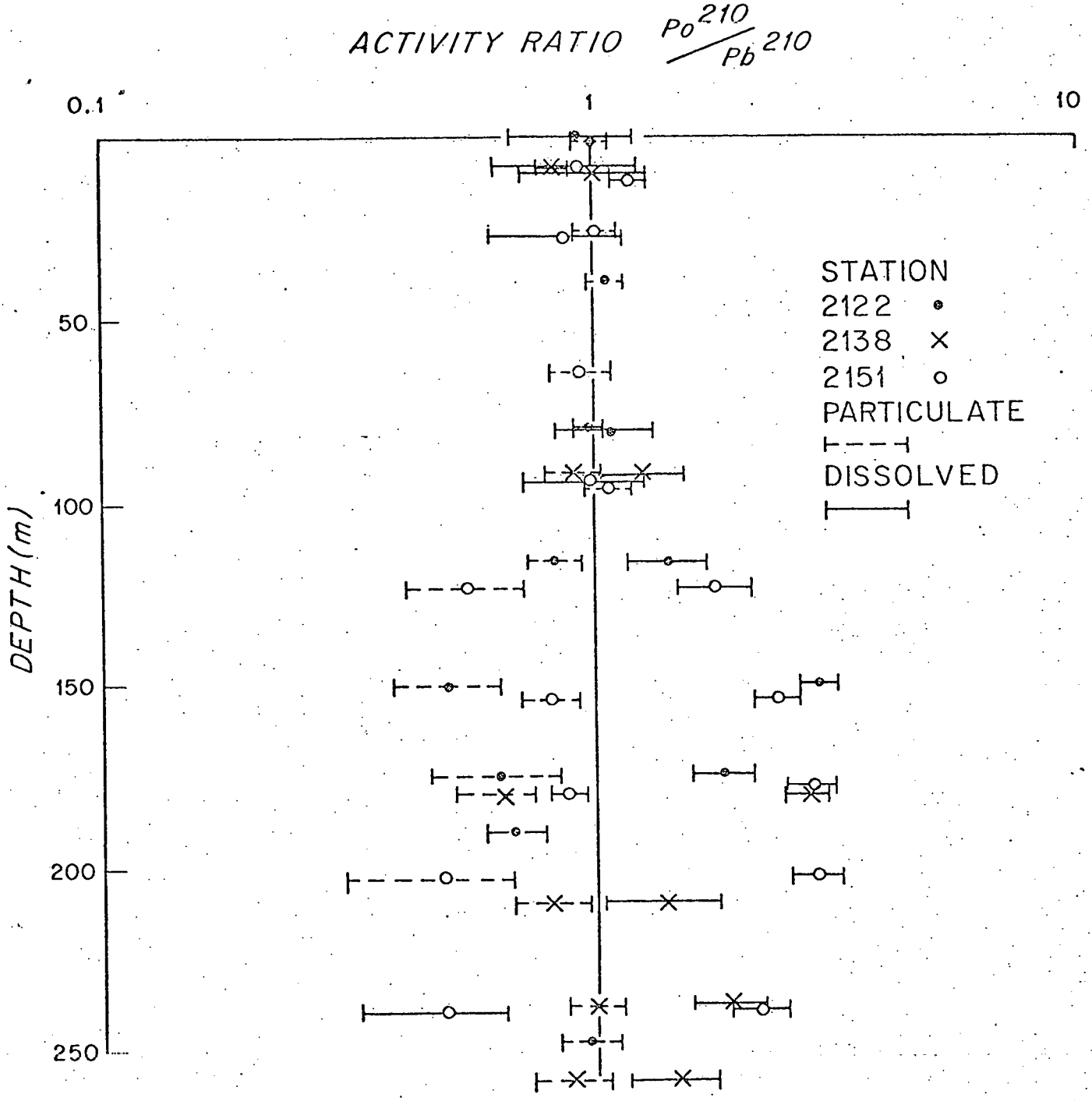

SILICATE μM/l
10
15
20
OXYGEN ml/l
4
5
6
PHOSPHATE μM/l
1.0
1.5
2.0
0
100
200
300
DEPTH (m)
WARM CORE
COLD CORE
OXYGEN
2122
2138
2151
SILICATE
2122
2138
2151
PHOSPHATE
2122
2138
2151

Figure 13



MURRAY – WILKINSON BASIN, GULF OF MAINE

Figure 14

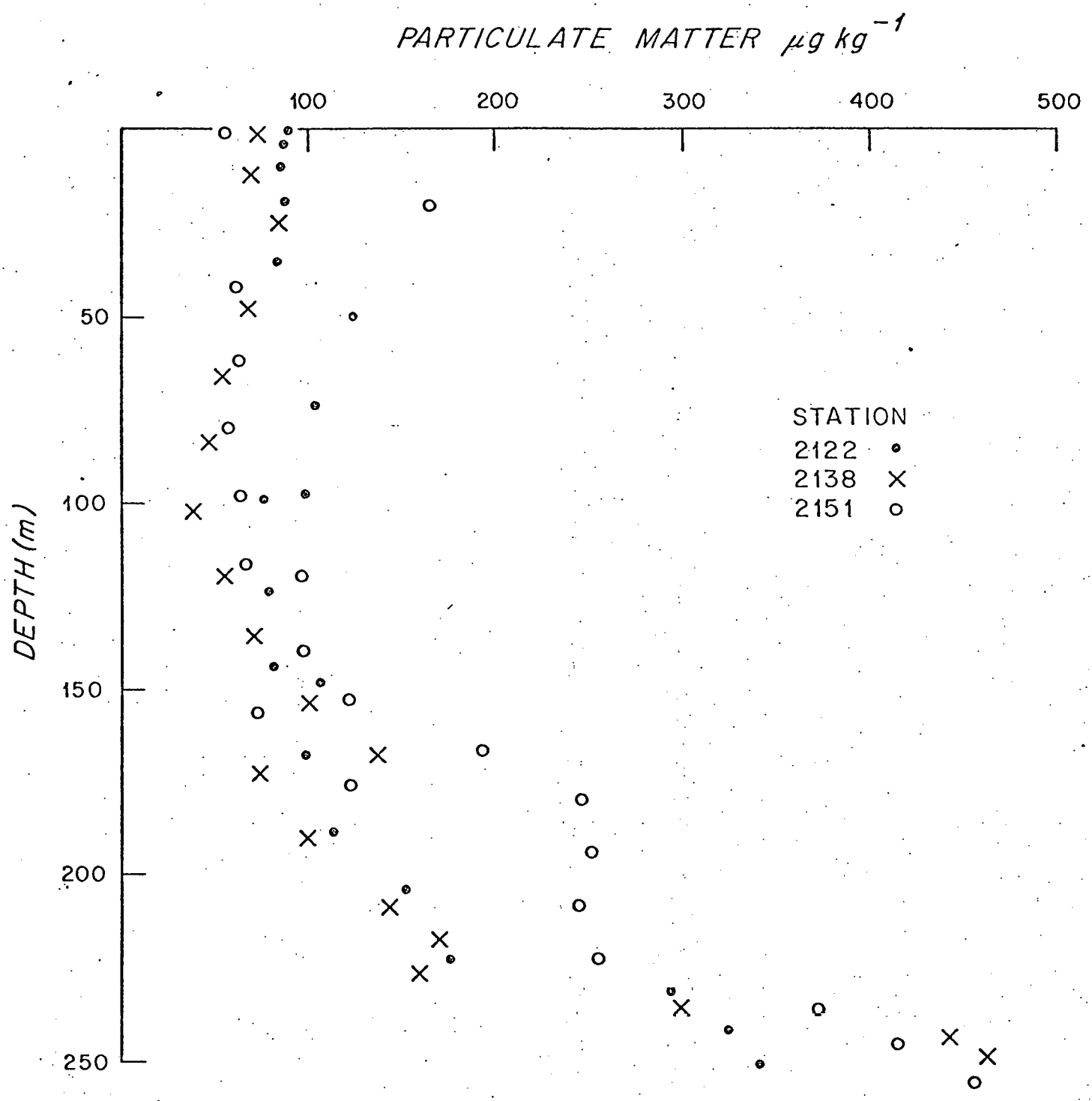

PARTICULATE MATTER μg kg⁻¹
100
200
300
400
500
50
100
150
200
250
DEPTH (m)
STATION
2122
2138
2151

Figure 15

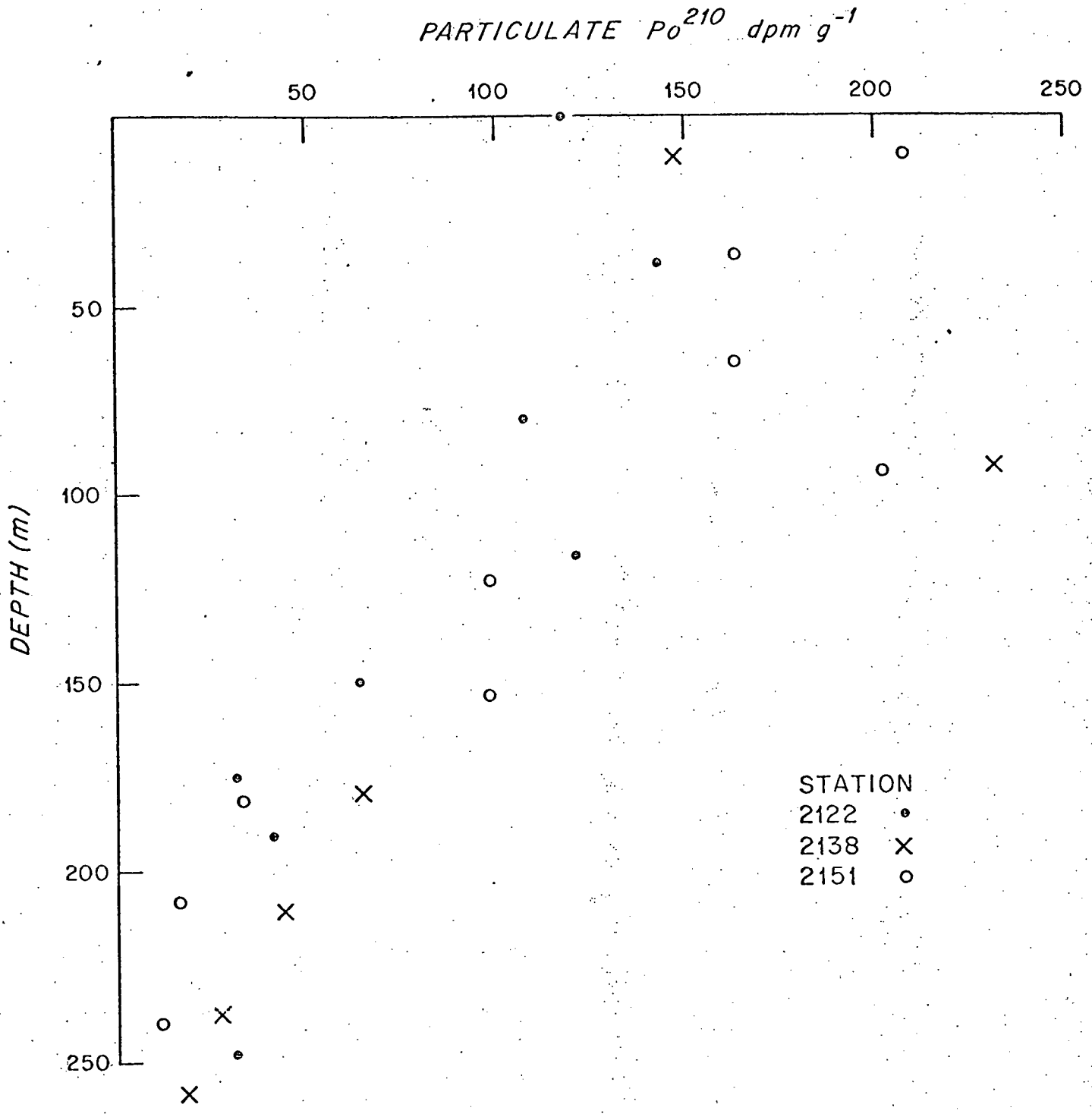

PARTICULATE Po^{210} dpm g^{-1}
50
100
150
200
250
DEPTH (m)
50
100
150
200
250
STATION
2122
2138
2151

Figure 16

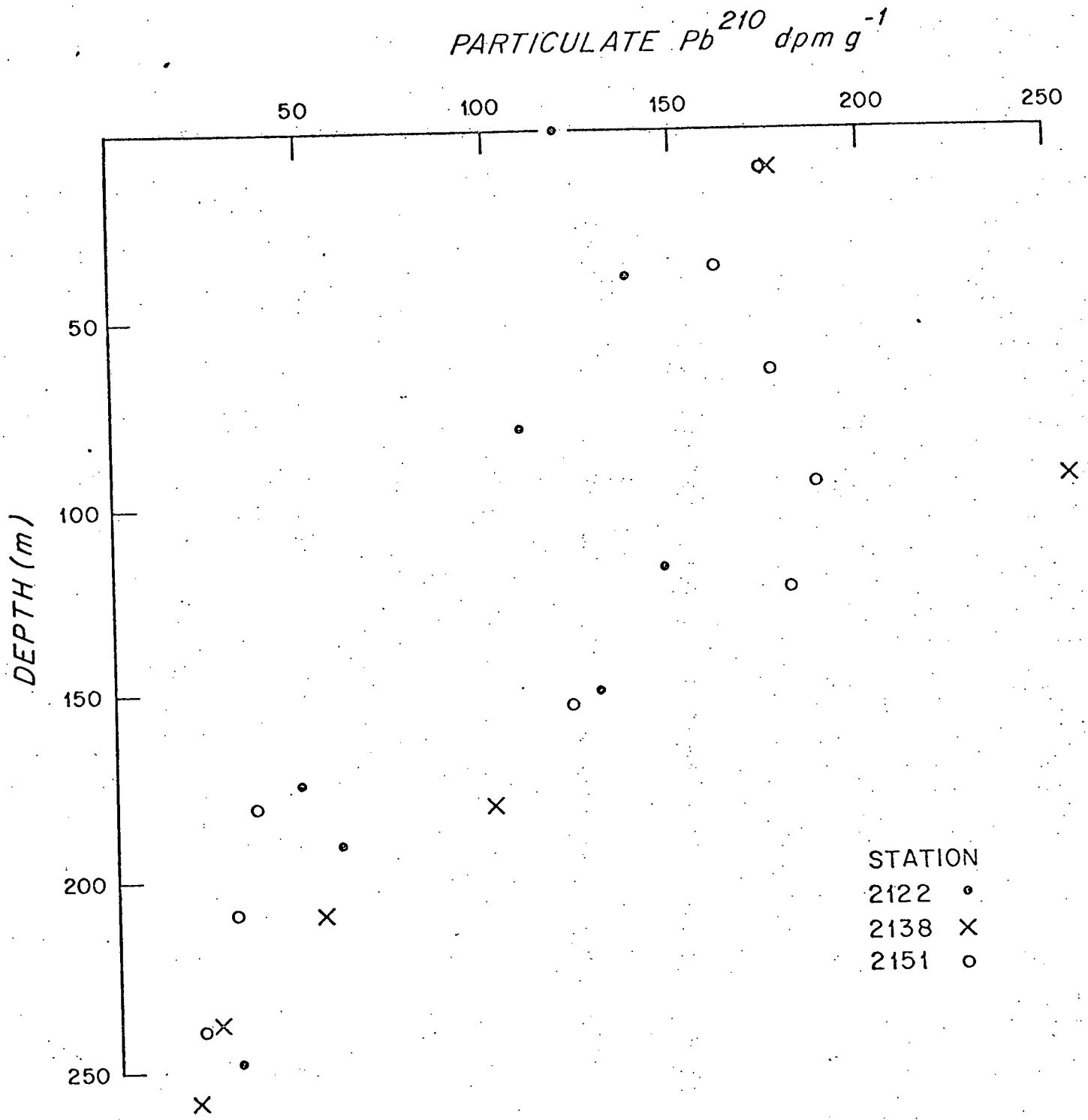

PARTICULATE Pb210 dpm g-1
50
100
150
200
250
DEPTH (m)
50
100
150
200
250
STATION
2122
2138
2151

Figure 17

3. FLEX 76 Program

A major fraction of our time for the last two months has been spent in cruise preparation for the FLEX 76 program.

This program, described in our last year's proposal, has already commenced and the latest FLEX ships schedule is appended. We plan to spend 28 days in the North Sea during KNORR Cruise 54 departing Ostend, Belgium on May 5 and arriving at Reykjavik, Iceland on June 4. A summary of our cruise plans and participants is attached, together with recent updates on the status of the program.

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COO-3566-15

$^{210}PB/^{226}RA$ AND $^{210}PO/^{210}PB$ DISEQUILIBRIA IN SEAWATER AND SUSPENDED PARTICULATE MATTER

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Running head: $^{210}Pb/^{226}Ra$ and $^{210}Po/^{210}Pb$ disequilibria...

ABSTRACT

The distribution of ^{210}Pb and ^{210}Po in dissolved (<0.4 micron) and particulate (>0.4 micron) phases has been measured at ten stations in the tropical and eastern North Atlantic and at two stations in the Pacific. Both radionuclides occur principally in the dissolved phase. Unsupported ^{210}Pb activities, maintained by flux from the atmosphere, are present in the surface mixed layer and penetrate into the thermocline to depths of about 500 m. Dissolved ^{210}Po is ordinarily present in the mixed layer at less than equilibrium concentrations, suggesting rapid biological removal of this nuclide. Particulate matter is enriched in ^{210}Po, with $^{210}Po/^{210}Pb$ activity ratios greater than 1.0, similar to those reported for phytoplankton. Box-model calculations yield a 2.5 y residence time for ^{210}Pb and a 0.6 y residence time for ^{210}Po in the mixed layer. These residence times are considerably longer than the time calculated for turnover of particles in the mixed layer (about 0.1 y). At depths of 100-300 m, ^{210}Po maxima occur and unsupported ^{210}Po is frequently present. Calculations indicate that at least 50% of the ^{210}Po removed from the mixed layer is recycled within the thermocline. Similar calculations for ^{210}Pb suggest much lower recycling efficiencies.

Comparison of the ^{210}Pb distribution with the reported distribution of ^{226}Ra at nearby GEOSECS stations has confirmed the widespread existence of a $^{210}Pb/^{226}Ra$ disequilibrium in the deep sea. Vertical profiles of particulate ^{210}Pb were used to test the hypothesis that ^{210}Pb is removed

from deep water by in situ scavenging. With the exception of one profile taken near the Mid-Atlantic Ridge, significant vertical gradients in particulate ^{210}Pb concentration were not observed, and it is necessary to invoke exceptionally high particle sinking velocities to account for the inferred ^{210}Pb flux. It is proposed instead that an additional sink for ^{210}Pb in the deep sea must be sought. Estimates of the dissolved $^{210}Pb/^{226}Ra$ activity ratio at depths greater than 1,000 m range from 0.2 to 0.8 and reveal a systematic increase, in both vertical and horizontal directions, with increasing distance from the sea floor. This observation implies rapid scavenging of ^{210}Pb at the sediment-water interface and is consistent with a horizontal eddy diffusivity of 3-6 x 10^7 cm^2/s. The more reactive element Po, on the other hand, shows evidence of rapid in situ scavenging. In filtered sea water, ^{210}Po is deficient, on the average, by ca. 10% relative to ^{210}Pb; a corresponding enrichment is found in the particulate phase. Total inventories of ^{210}Pb and ^{210}Po over the entire water column, however, show no significant departure from secular equilibrium.

1. Introduction

Several recent papers (1-4) have demonstrated the possibility of using members of the natural radioactive decay series to study the fate of certain reactive elements introduced to the oceans. One of the principal advantages of using such tracers is that they are supplied to the oceans by in-situ decay of their parent nuclides, and their rates of supply can thus be accurately determined. Lead-210 ($t_{1/2}$ = 22.2 y) and polonium-210 ($t_{1/2}$ = 138.4 d) are especially suitable, because their half-lives are long enough for measurable radioactive disequilibria to be maintained by processes operating in the oceans, but short enough that their activities in seawater can be measured with reasonable ease.

Lead-210 is produced throughout the water column following the decay of radium-226, and it is also introduced to the sea surface from the atmosphere, where it is formed by decay of radon-222. Virtually all of the ^{210}Po in seawater is formed in situ by decay of ^{210}Pb.

The fate of ^{210}Pb that enters the sea surface was first examined by Rama et al. (5) , who measured ^{210}Pb concentrations in surface seawater from the northwest Pacific. They took the annual flux of ^{210}Pb to the sea surface to be 0.5 dpm/cm^2 and pointed out that this rate of supply is much larger than the rate of ^{210}Pb production from decay of ^{226}Ra in the mixed layer, taken to be 100 m in thickness. A simple box-model calculation led to a 2 y residence time for ^{210}Pb in the mixed layer.

Shannon et al. (2) measured ^{210}Pb and ^{210}Po in seawater and plankton collected off southwest Africa. Activity ratios $^{210}Po/^{210}Pb$ in surface

seawater averaged 0.5 and indicated a 0.6 y residence time for ^{210}Po. Both phytoplankton and, to a larger extent, zooplankton were found to be enriched in ^{210}Po relative to ^{210}Pb. This enrichment of ^{210}Po has been used to explain the more rapid turnover of this nuclide in surface seawater (2, 6).

Craig et al. (4) discovered a pronounced deficiency of ^{210}Pb in the deep sea, averaging 50% of the equilibrium value. This condition of radioactive disequilibrium was present in profiles from both the Atlantic and Pacific and was concluded to be a worldwide phenomenon. It was suggested that ^{210}Pb in the deep ocean is continually removed as a result of scavenging by sinking particles. Application of a vertical advection-diffusion model, with allowance for radioactive growth and decay, yielded a 54 y residence time for ^{210}Pb in the deep Pacific. A similar value (about 40 y) resulted from a box-model calculation for the Atlantic.

Despite the importance that has been attached to the role of particulate matter in transporting ^{210}Pb, ^{210}Po and certain other radionuclides to the sediments, very few radiochemical analyses of this material have been reported. As a consequence there exist in the literature contradictory interpretations of residence times calculated on the basis of daughter/parent activity ratios measured in unfiltered seawater samples. Bhat et al. (1) discovered a $^{234}Th/^{238}U$ disequilibrium in surface sea water and used their data to calculate a ^{234}Th sinking velocity. Matsumoto (7) pointed out that this interpretation was incorrect, because they had assumed all of the ^{234}Th to be in particulate form. Craig et al.

(4) assumed that only a small fraction of the total ^{210}Pb in seawater is contained in particulate phases and that their 54 y residence time for ^{210}Pb in the deep water applied to the transfer of ^{210}Pb from solution to the sinking particles. It was implied that the particles must sink very rapidly. Tsunogai et al. (8), on the other hand, obtained similar data but interpreted them in terms of a very slow settling velocity. These two interpretations are clearly not compatible, because they imply very different distributions of ^{210}Pb between dissolved and particulate phases.

Recently Applequist (9) showed that indeed only 5-10% of the ^{210}Pb in the deep sea is contained in particles of diameter greater than 0.4 micron, as assumed by Craig et al. (4), and he showed further that particulate ^{210}Pb activities tend to increase with depth at two stations in the Pacific, in qualitative agreement with their model. However, particle sinking velocities required to satisfy the model were not determined.

In this paper we discuss new data, acquired from GEOSECS samples, on the distribution of ^{210}Pb and ^{210}Po between dissolved and particulate phases in seawater. We will consider the removal of these nuclides from the surface mixed layer, their fate once transported to deeper levels and the question of scavenging within the deep ocean.

2. Sampling and analytical methods

Sampling was performed in the Atlantic during cruise 32 of F/S "Meteor" in November and December of 1973. This cruise was one of the

West German contributions to the GEOSECS program. Additionally, samples were obtained from GEOSECS Pacific stations 226 and 320. "Meteor" station locations are shown in Figure 1.

Samples were taken with 270-l stainless-steel Gerard barrels or, in the case of many of the deeper "Meteor" samples, pairs of 30-l PVC Niskin bottles spaced 5-10 meters apart on the wire. Suspended matter was sampled by pumping 40-100 liters of seawater through 142-mm diameter, 0.4-micron pore-size Nuclepore filters. Filtration aboard "Meteor" was ordinarily completed within one to three hours following collection, but longer times often elapsed during the Pacific GEOSECS cruise. Changes in the distribution of ^{210}Pb and ^{210}Po activity that may occur when filtration is delayed have been discussed (9, 10), and they are not considered large enough to seriously bias the interpretations that will follow.

Twenty-liter aliquots of filtered water were drawn into plastic vessels containing enough concentrated HCl to bring the pH within the range 1.5-2.0. The samples were then spiked with known amounts of ^{208}Po (a few dpm) and stable Pb (a few mg) tracers and stored for later treatment. Excess water was removed from the filters by applying mild suction, and the filters were folded and sealed in plastic bags.

Analytical methods have already been described in detail (10), so only a brief summary is given here. Extraction of the Pb and Po isotopes from seawater was accomplished by APDC chelate co-precipitation (11) followed by filtration with Millipore filters and wet combustion.

Particulate matter samples were decomposed with mixtures of mineral acids. Samples were then dissolved in 2N HCl, and Po was plated on silver discs (12) and counted with silicon surface-barrier detectors. The sample solutions were then stored for several months during which ^{210}Po was re-generated by decay of ^{210}Pb. Determination of this newly produced ^{210}Po gave a measure of the ^{210}Pb present in the sample. Recovery of the added Pb carrier was determined by atomic absorption spectrophotometry.

3. Results

Analytical results for the "Meteor" samples are given in a separate report (13). Representative profiles are shown in Figures 2 a-d. The Pacific GEOSECS results are presented in Tables 1 and 2 and Figures 3 and 4.

For many of the GEOSECS 226 samples the measured particulate activities exceeded the dissolved activities, a behavior unlike that found for any of the Atlantic stations, and the profiles were extremely erratic. It was noted that many of the filters received from this station were heavily loaded with particles of rust, which were evidently produced by corrosion of various pieces of hardware inadvertently dropped into the Gerard barrels during the cruise. These rust particles probably introduced minimal contamination, but newly formed iron hydroxides do act as efficient scavengers for Pb and Po in seawater. Some of the lowest activities measured in the filtered water correspond to the highest activities found on the filters (note especially the 533 m sample and

samples at 2999 m and below). It is, of course, impossible under these circumstances to determine the original distribution of activity between dissolved and particulate phases. Consequently, for this station, dissolved and particulate analyses have been combined and reported as total activities. The results are still rather badly scattered, and large errors could have arisen from uneven distribution of the rust particles within the water samples. Systematic losses to surfaces of corroded objects within the barrels could also have occurred. Because the other GEOSECS profile (Station 320) did not include particulate samples, the extent to which this problem may be common to all of the GEOSECS samples is not known. Applequist (9) has presented two GEOSECS profiles (Stations 201 and 314) in which a fairly consistent distribution of ^{210}Pb between dissolved and particulate phases can be seen. Of the other GEOSECS samples that he examined, only occasional filters showed evidence of serious interference by rust particles. Nonetheless, in the absence of particulate analyses from Station 320, all of the GEOSECS results reported here must be regarded with some suspicion. Fortunately it appears that foreign objects were, for the most part, excluded from the Gerard barrels during the "Meteor" cruise. One questionable sampler, however, was noted (13).

Radium analyses of the "Meteor" samples are being made at the University of Heidelberg, but the results are not yet available for inclusion in this report. Consequently, ^{226}Ra distributions at the

"Meteor" stations have been estimated from distributions at nearby GEOSECS stations measured at the Lamont-Doherty Geological Observatory (W. S. Broecker et al., unpublished data). For the purpose of extrapolating the measured ^{226}Ra profiles to the "Meteor" station locations, the similarity of ^{226}Ra and Si distributions (14) has been used. Figure 5 is a plot of ^{226}Ra versus Si for the four available profiles that lie closest to the "Meteor" track. For each of the stations a linear relationship between ^{226}Ra and Si is defined, and all of the correlations for the individual stations are significant at a confidence level greater than 99%. Linear regression coefficients and y-intercepts along with their 95% confidence limits are summarized in Table 3. The regression lines for Stations 29 and 40 are seen to be nearly identical as are the two lines for Stations 107 and 115. However, these two pairs of stations, which are located on opposite sides of the Mid-Atlantic Ridge, show a difference between them in the Ra-Si relationship that is significant at the 95% confidence level. Therefore, in estimating the ^{226}Ra distribution from the measured Si distribution at the "Meteor" stations, two different relationships, obtained by combining the data from each pair of GEOSECS stations, have been used. For stations west of the Mid-Atlantic Ridge (Me-32-8, 12, 15, 18), the equation used is $Ra = 7.86 + .142\ Si$, where Ra is in dpm/100 kg, and Si is in um/kg. For stations east of the ridge (Me-32-21, 22, 23, 27, 32, 34), the relationship is $Ra = 6.91 + .217\ Si$. The standard error for predicting

Ra from Si, based on the variance about the regression, is in the range 0.8-1.0 dpm/100 kg (5-10% of the predicted value). The ^{226}Ra activity estimated for deep water of the Venezuelan Basin (Me-32-12) is 11.8 dpm/100 kg and compares very well with the average value of 12.2 dpm/100 kg measured by Szabo et al. (15). In addition, values estimated for Me-32-8 are in excellent agreement with their results for stations north of the Greater Antilles.

4. The fate of ^{210}Pb and ^{210}Po in the upper layers of the ocean

Results obtained from surface water samples vary considerably from one station to the next, and there are strong indications that horizontal advection and non-steady-state processes influence ^{210}Pb and ^{210}Po distributions at shallow depths (10). It is therefore unlikely that a simple treatment of data from individual stations will yield meaningful results. However, it is believed that, by averaging the data over a large enough region, these effects may be minimized and that a general picture of the processes controlling the mean distribution of ^{210}Pb and ^{210}Po in the upper layers of the sea can be developed.

The sub-surface distribution of ^{210}Po is shown in Figure 6, where activity differences have been plotted for Me-32 Stations 8-27. It is seen that within the upper 100 m of the water column nearly all of the data indicate a ^{210}Po deficiency. This is a zone of net removal of ^{210}Po from solution. Between the depths of 100 and 300 m, a systematic ^{210}Pb enrichment is found, indicating a net supply of ^{210}Po by processes

other than radioactive decay. These two regions correspond approximately to the mixed layer and the thermocline in this region of the Atlantic.

The approach to be adopted is to compute arithmetic averages for all the data points in each of these two segments of the water column and for all of the stations plotted in Figure 6. These stations lie between 14 and 22°N, and the structure of the water column is similar for all of them. Station 32 has been omitted, because it lies at a higher latitude and the mixed layer is considerably thicker. In Table 4 are listed standing crops of ^{226}Ra, ^{210}Pb and ^{210}Po in each of the two layers considered. Also given are the same quantities calculated for other choices of the boundary depths. These quantities will be entered in the material balance calculations that follow. Throughout these calculations ^{226}Ra, ^{210}Pb and ^{210}Po are designated by the subscripts 1, 2 and 3, respectively. Dissolved and particulate activities, A^d and A^p, are in units of dpm/cm^2 and are read directly from Table 4. These units are chosen so that fluxes for different reservoir sizes may be directly compared. Net rates of transfer between the dissolved and particulate phase are given by J in dpm/cm^2 y, which is taken to be positive when the net transfer is from the particulate to the dissolved phase. Removal of the nuclides in particulate form is designated by the symbol P. Residence times are given by τ and always refer to the net sum of removal processes other than radioactive decay. As a first approximation we neglect fluid exchange across the boundaries. Numerical substitutions

will be shown throughout so that the relative importance of each term in the material balance can be evaluated.

We consider first the material balance for dissolved ^{210}Po in the upper 100 m of the water column, and we have:

$$\lambda_3 A_2^{\,d} + J_3 = \lambda_3 A_3^{\,d} \qquad (1)$$

which states that production of ^{210}Po by radioactive decay of ^{210}Pb in solution is balanced by radioactive decay and transfer of ^{210}Po to the particulate phase. The flux of ^{210}Po from the atmosphere is only about 10% that of ^{210}Pb (16) and may be neglected in the present calculation. This assumption will be verified when the numerical value of the ^{210}Pb flux is estimated below. Moreover, partial cancellation of this flux by escape of ^{210}Po across the sea surface has been suggested (6). Substitution of numerical values in equation (1) gives:

$$2.67 + J_3 = 1.41$$

$$J_3 = -1.26 \text{ dpm/cm}^2 \text{ y}$$

The net flux J is negative, indicating that ^{210}Po is removed from solution to particles in the mixed layer. The residence time for ^{210}Po in solution is given by:

$$\tau_3^{\,d} = A_3^{\,d}/-J_3 = 0.61 \text{ y} \qquad (2)$$

This result is in good agreement with other estimates (2, 6).

For particulate ^{210}Po we assume that supply by decay of particulate ^{210}Pb and by transfer from solution is balanced by radioactive

decay and removal of particles from the mixed layer, and we write:

$$\lambda_3 A_2^P - J_3 = \lambda_3 A_3^P + P_3$$
$$0.12 + 1.26 = .23 + P_3 \qquad (3)$$
$$P_3 = 1.15 \text{ dpm/cm}^2 \text{ y}$$

The residence time for particulate ^{210}Po is:

$$\tau_{Po}^P = A_3^P / P_3 = .11 \text{ y} \qquad (4)$$

We note that this time is much shorter than the residence time of ^{210}Po in the dissolved phase.

If it is assumed that ^{210}Pb is removed from the mixed layer by particles having a residence time similar to those that carry ^{210}Po, it is possible to determine the flux of particulate ^{210}Pb from the mixed layer:

$$P_2 = (A_2^P / A_3^P) P_3 \qquad (5)$$
$$= (0.063/0.126)\ (1.15) = .58 \text{ dpm/cm}^2 \text{ y}$$

The assumption adopted here was first suggested by Turekian et al. (6), who used activity ratios measured in zooplankton, rather than total suspended matter, as an indication of the relative downward fluxes for the two nuclides.

Constructing a material balance for particulate ^{210}Pb and entering the above value for P_2, we have:

$$-J_2 = \lambda_2 A_2^P + P_2 \qquad (6)$$
$$= 0.002 + 0.58$$
$$J_2 = -0.58 \text{ dpm/cm}^2 \text{ y}$$

Finally the dissolved ^{210}Pb balance is considered, the unknown term here being the rate of input from the atmosphere, I_a, which, for the moment, we consider to be soluble:

$$\lambda_2 A_1 + I_a + J_2 = \lambda_2 A_2^d \qquad (7)$$

$$0.02 + I_a - 0.58 = 0.05$$

$$I_a = 0.61 \text{ dpm/cm}^2 \text{ y}$$

The residence time of ^{210}Pb in solution is:

$$\tau_2^d = A_2^d / -J_2 = 2.5 \text{ y} \qquad (8)$$

In equation (7) we have neglected the effect of radon escape across the sea surface, which would reduce the rate of ^{210}Pb production by decay of ^{226}Ra by about 25% (17). Because the radioactive production term is very small, however, the error introduced is insignificant. Estimates of the ^{210}Pb residence time in the mixed layer and the rate of ^{210}Pb delivery from the atmosphere given above are in good agreement with those of other authors (2, 5). Calculations similar to those made here were made by Turekian et al. (6), who obtained much lower estimates of the atmospheric delivery rate (0.05-0.10 dpm/cm^2 y) and longer ^{210}Pb residence times (9.4-24 y). The difference lies in their use of $^{210}Po/^{210}Pb$ ratios in zooplankton, which are commonly a factor of 5 higher than in total suspended matter. Reconsideration of the problem (18) led them to conclude that zooplankton are not a reliable indicator of relative fluxes out of the mixed layer, a conclusion that is supported here.

We now consider the possibility that ^{210}Pb delivered from the atmosphere enters the sea surface in particulate form. For dissolved ^{210}Pb

in the mixed layer, we assume no soluble input, and we may omit I_a and determine J_2:

$$\lambda_2 A_1^{\,d} + J_2 = \lambda_2 A_2^{\,d} \qquad (9)$$

$$J_2 = 0.05\text{-}0.02 = 0.03 \text{ dpm/cm}^2 \text{ y}$$

Here J_2 becomes positive, indicating a net transfer of ^{210}Pb from particles to solution, as required to maintain the dissolved ^{210}Pb excess observed in the mixed layer. The material balance for particulate ^{210}Pb is then used to determine the atmospheric input:

$$I_a - J_2 = \lambda_2 A_2^{\,P} + P_2 \qquad (10)$$

$$I_a - 0.03 = 0.002 + 0.58$$

$$I_a = 0.61 \text{ dpm/cm}^2 \text{ y}$$

The estimate of I_a remains essentially unchanged.

We may now consider the sub-surface layer between 100 and 300 m, which is a region of net release of ^{210}Po to solution. For dissolved ^{210}Po we have:

$$\lambda_3 A_2^{\,d} + J_3 = \lambda_3 A_3^{\,d} \qquad (11)$$

$$4.61 + J_3 = 5.38$$

$$J_3 = 0.77 \text{ dpm/cm}^2 \text{ y}$$

The flux of ^{210}Po released from particles in this region, J_3, represents 67% of the flux leaving the surface mixed layer. This percentage will be referred to as the re-cycling efficiency. A similar calculation for ^{210}Pb gives:

$$\lambda_2 A_1 + J_2 = \lambda_2 A_2^{\,d} \qquad (12)$$

$$0.050 + J_2 = 0.079$$

$$J_2 = 0.029 \text{ dpm/cm}^2 \text{ y}$$

The amount of ^{210}Pb re-cycled is small, and a re-cycling efficiency of about 5% is indicated. Even this value may be overestimated, because we have neglected sub-surface delivery of ^{210}Pb by vertical or horizontal mixing processes.

The results obtained from the above calculations are summarized in Table 5 along with results for different choices of the boundary depths. The dependency on the choice of reservoir size is small.

5. Deep-sea scavenging of ^{210}Pb and ^{210}Po

5.1 Rate of ^{210}Pb removal

In deep-ocean water we find ^{210}Pb always to be depleted relative to its parent ^{226}Ra, in agreement with previous observations (4, 8). To explain these sub-equilibrium concentrations, it is necessary to postulate processes other than radioactive decay that remove ^{210}Pb from the deep sea, and it is the rate of this non-radioactive removal that we wish to estimate. We begin by considering the dissolved ^{210}Pb profiles (Figures 2-4). Unsupported ^{210}Pb delivered from the atmosphere penetrates to appreciable depths in the water column. The influence of this source, however, appears to become small as depths of 500-1,000 m are approached (generally in the lower part of the thermocline), and ^{210}Pb profiles frequently pass through minima at these depths. In defining the deep-water column, therefore, we shall take this level as the upper boundary and assume that the net diffusive exchange across it is negligibly small. (In applying their advection-diffusion model to ^{210}Pb and ^{226}Ra profiles

from the Pacific, Craig et al. (4) showed that ^{210}Pb losses across the upper and lower boundaries were insignificant relative to the inferred rates of removal within their mixing regime. Such a model, however, is inappropriate in the Atlantic, and in treating the dissolved ^{210}Pb data we adopt what is essentially a box-model approach.) The lower boundary of the deep water column in set at the sea floor.

The principal source of ^{210}Pb in the deep sea is the in situ decay of ^{226}Ra, and rates of production from this source are calculated by integrating ^{226}Ra profiles over the height of the deep water column. Integrations were performed simply by dividing the water column into intervals defined by the midpoints between sampling depths and weighting each data point according to the depth interval it represented. Integrated ^{226}Ra and ^{210}Pb activities are given in Table 6 for all stations at which both dissolved and particulate ^{210}Pb were measured throughout the water column. Also listed are similar results for two Pacific GEOSECS stations, based on data of Applequist (9). Rates of ^{210}Pb production from ^{226}Ra are given, in activity units, by $\lambda_2 A_1$, where λ_2 is the ^{210}Pb decay constant (0.0312 y^{-1}) and A_1 is the ^{226}Ra activity. These rates vary from 1.2-1.9 dpm/cm^2 y for the Atlantic stations and are about twice as high for the Pacific, where ^{226}Ra concentrations are higher.

Two additional sources of ^{210}Pb in the deep sea need to be considered: 1) release from particles sinking from the surface and 2) generation near the sea floor by decay of excess ^{222}Rn. Because of the short

residence time of ^{210}Pb in the mixed layer, the flux of particulate ^{210}Pb entering the deep water reservoir is approximately equal to the rate of atmospheric ^{210}Pb deposition at the sea surface. This flux was estimated above to be approximately 0.6 dpm/cm^2 y for the tropical North Atlantic. It was also seen that redissolution of ^{210}Pb in the thermocline is insignificant, and by extrapolation we assume that this conclusion also holds for the deep ocean. There is no way to verify this assumption, because the deep water disequilibrium reflects only the net effect of supply and removal processes and is always in a direction indicating net removal of ^{210}Pb from solution. However, the assumption is not of crucial importance in the discussion that follows, because, in evaluating the in situ scavenging hypothesis, we are concerned principally with the net effects.

The standing crop of excess ^{222}Rn, maintained by the flux of unsupported ^{222}Rn from the sediments, ranges from 0.2-20 dpm/cm^2 (19) and produces ^{210}Pb at rates ranging from 0.006-0.6 dpm/cm^2 y. Radon fluxes tend to be highest in regions of low sedimentation rate, and the highest values measured are from the Pacific (19). A typical value for ^{210}Pb production from excess ^{222}Rn in the Atlantic is 0.1 dpm/cm^2 y.

Because release of ^{210}Pb from particles and production from excess ^{222}Rn appear to be relatively small, we shall assume that all of the ^{210}Pb in the deep sea is derived from in situ decay of ^{226}Ra. Lead-210 decay in solution is given by $\lambda_2 A_2$, where A_2 is the dissolved ^{210}Pb activity, and the difference $\lambda_2 A_1 - \lambda_2 A_2$ is the rate of removal of

^{210}Pb from solution by processes other than radioactive decay. Calculated values of this removal rate are given in Table 6 along with apparent residence times given by $A_2/\lambda_2\ (A_1-A_2)$. These residence times are in fair agreement with the value of about 40 y estimated by Craig et al. (4) for the Atlantic and their value of 54 y for the Pacific, but significant differences between stations are apparent, as will be discussed below.

5.2 In situ scavenging of ^{210}Pb

The removal rates listed in Table 6 represent fluxes of ^{210}Pb from solution that must be accounted for by processes other than radioactive decay. If it is assumed that this removal is maintained entirely by in situ scavenging, then it should be possible to estimate particle sinking rates from particulate ^{210}Pb profiles. For simplicity we assume that ^{210}Pb is transferred at a constant rate R (dpm/m^3 y) from solution to particles. Actually, according to the in situ scavenging hypothesis, the divergence of ^{226}Ra and ^{210}Pb profiles toward the bottom implies that the rates of scavenging increase somewhat with depth, but we shall use the average rate, which is obtained by dividing the profile integrations of Table 6 by the height of the water column. Particles are assumed to sink at a constant rate S (m/y). The rate of change of particulate ^{210}Pb concentration P with depth z (positive downward) is given by:

$$dP/dz = R/S - \lambda_2 P/S \qquad (13)$$

in which R/S is the rate of gain by transfer from solution, and $\lambda_2 P/S$

is the rate of loss due to radioactive decay. Setting $z = 0$ and $P = P_0$ at the upper boundary, we have the solution :

$$R-\lambda_2 P = (R-\lambda_2 P_0) \exp(-\lambda_2 z/S) \qquad (14)$$

As z becomes large, P must approach the limiting value R/λ_2, for which radioactive decay is just balanced by transfer from solution.

It is clear that for ^{210}Pb deficiencies to be maintained in the deep sea by in situ scavenging, dP/dz must be positive; i.e., for any segment of the water column, the total ^{210}Pb increment due to transport by sinking must be negative. Of the six complete particulate ^{210}Pb profiles from the Atlantic (Me-32-12, 15, 18, 23, 27, 32), only one (Me-32-18) shows a significant increase in activity with depth. This anomalous station is located close to the Mid-Atlantic Ridge and will be discussed below. For the other five profiles, it is possible that positive gradients exist but are simply not detectable. For this to be the case, however, high sinking velocities would be required. Table 7 indicates how large these sinking velocities must be to account for the observed profiles. Equation (14) has been fitted to the particulate ^{210}Pb profiles and 2σ confidence limits on the settling velocity have been calculated. A typical case is illustrated in Figure 7, where profiles to be expected for other settling velocities are also drawn for the same initial condition. Because the gradients are so small, and in some of the cases even slightly negative, it is generally possible only to assign lower limits to the apparent sinking rate. It is clear, however, that settling velocities of several thousands of

meters per year must be invoked if ^{210}Pb removal is to be accounted for by particulate flux alone.

These settling velocities are about an order of magnitude larger than those estimated for other radioactive tracers. For example, Krishnaswami et al. (20) measured ^{230}Th and ^{234}Th in particulate matter samples from the deep Pacific. From their ^{234}Th results it was demonstrated that Th isotopes are very rapidly transferred to particles following their production from U isotopes dissolved in seawater. Particulate ^{230}Th profiles showed the expected increase with depth, and a settling velocity of about 600 m/y was calculated. This estimate represents an upper limit for comparison with data obtained with 0.4 micron Nuclepore filters, because their filters collected only particles larger than 1.2 micron in diameter.

If the sinking velocities calculated in Table 7 are unreasonably high, then an alternative explanation for the near zero vertical gradients observed in particulate ^{210}Pb profiles must be sought. In applying equation (14) we have assumed that R, the rate of solution-to-particle transfer, is defined by the extent of the dissolved $^{210}Pb/^{226}Ra$ disequilibrium, and in this case R is always much greater than $\lambda_2 P$ (i.e., particulate ^{210}Pb activities account for only a small fraction of the dissolved ^{226}Ra-^{210}Pb activity difference). As noted above, particulate ^{210}Pb activities should approach a limiting value for which $R = \lambda_2 P$. This is the condition for which uptake from solution is compensated by radioactive decay, and it is here suggested that such a

condition may already have been reached in the Atlantic by particles entering the deep sea. If this is the case, then it is possible to calculate the rate of in situ scavenging from the average particulate ^{210}Pb activity in the deep water. Values of R calculated in this manner are given in Table 8 and compared with those determined earlier by considering the dissolved ^{226}Ra-^{210}Pb differences. When in situ scavenging fluxes are estimated in this way, 90-95% of the dissolved ^{210}Pb/^{226}Ra disequilibrium remains unaccounted for, and an additional sink for ^{210}Pb in the deep sea must be sought.

We have so far not considered the possibility that particulate ^{210}Pb may be supported by ^{226}Ra. Particulate ^{226}Ra concentrations in deep Pacific water are in the range 0.01-0.04 dpm/100 kg (20) and thus do not exceed 20% of the particulate ^{210}Pb concentrations. If allowance were to be made for this additional contribution, estimates of R would be even further reduced.

5.3 Lead-210 scavenging at the sediment-water interface

It was noted by Craig et al. (4) that some of the lowest ^{210}Pb concentrations in their Pacific profile occur near the bottom, where large quantities of excess ^{222}Rn also are present, and they suggested that rapid scavenging of ^{210}Pb must occur in this region. A similar effect is seen in the Atlantic profiles, which consistently show a greater extent of disequilibrium as the sea floor is approached. Craig et al. (4) also pointed out, however, that the influence of boundary scavenging extends upward, by vertical mixing, only to a height of about 1000 m

from the bottom. Within their mixing regime (1791-4100 m, 200 m above the bottom), less than 5% of the ^{210}Pb removal could be accounted for by vertical mixing across the boundaries, and it was concluded that the remainder must be accounted for by in situ scavenging and radioactive decay. What is not considered in a vertical model such as theirs is that, if boundary scavenging is effective to heights of 1000 m from the bottom, then it may also be of importance at appreciable distances from lateral boundaries.

Let us consider the case in which ^{210}Pb is scavenged at some topographic boundary, such as a continental margin or mid-ocean ridge, and allow for in situ production from ^{226}Ra decay and consumption by transfer to suspended particles. Neglecting the effects of advection, we have, at steady-state:

$$K_H \, \partial^2 A_2/\partial x^2 + \lambda_2 A_1 = (\lambda_2+k)A_2 \qquad (15)$$

where K_H is the horizontal eddy diffusivity, and k is the rate constant for in situ scavenging (assumed to be first-order). As x approaches infinity, the activity ratio A_2/A_1 is determined solely by the rate of in situ scavenging and approaches the value $\lambda_2/(\lambda_2+k)$. With the additional boundary condition that $A_2 = A_{2,0}$, and for A_1 constant, we have the solution

$$\frac{\lambda_2}{\lambda_2+k} - \frac{A_2}{A_1} = \left(\frac{\lambda_2}{\lambda_2+k} - \frac{A_{2,0}}{A_1}\right) \exp\left(-\sqrt{\frac{\lambda_2+k}{K_H}}\, x\right) \qquad (16)$$

Figure 8 shows a plot of A_2/A_1 versus distance to the nearest topographic boundary. The need to consider sources of ^{210}Pb other than ^{226}Ra decay as well as the effects of local scavenging at the bottom has been

avoided by including data only from depths greater than 1000 m below the surface and greater than 1000 m above the bottom. Distances were determined by plotting station locations on a bathymetric chart and measuring distances to the nearest contours at 1000 m intervals. Interpolations were performed for intermediate sampling depths. The figure clearly shows a significant correlation between the $^{210}Pb/^{226}Ra$ activity ratio (or the apparent ^{210}Pb residence time) and horizontal distance from the assumed ^{210}Pb sink.

The curve drawn in Figure 8 was obtained by adjusting K_H and k in equation (16) until the best fit was obtained. For this purpose it must be assumed that, at any depth, the ^{226}Ra concentration does not vary along a horizontal line between a given station and its nearest intersection with the sea floor. This assumption and the use of the activity ratio A_2/A_1 allow data from different regions to be compared on the same diagram. The best fit was obtained for $K_H = 5.6 \times 10^7$ and $k = 0.005$. This value for k corresponds to a residence time for ^{210}Pb with respect to in situ scavenging of 200 years. It is clear that while the general curve represented by the data in Figure 8, from 500 to 4000 km, is reasonably represented by this solution the data at less than 500 km appear to have a steeper slope than can be accounted for by any solution of equation (15).

It is well known that the eddy diffusion process in the ocean is non-Fickian and Okubo (30) has suggested a relationship between the apparent eddy diffusion coefficient, Ka cm^2 sec^{-1}, and the scale length, ℓ cm, as

$$Ka = 0.0103\ell^{1.15} \qquad (17)$$

such that at shorter scale lengths the apparent eddy diffusion coefficient is smaller. With variable K_H equation (15) would be

$$\frac{\partial}{\partial x}\left(K_H(x)\frac{\partial A_2}{\partial x}\right) + \lambda_2 A_1 = (\lambda_2+K)A_2 \qquad (18)$$

An analytical solution of this equation is difficult to find but in Figure 8 we show two numerical solutions obtained using the boundary conditions $A_2/A_1 = 0.32$, $x = 150$ km and $A_2/A_1 = 0.78$, $x = 4500$ km, and where $K_H(x)$ is given by the Okubo relationship. The numerical approximation was obtained using Hamming's modified predictor-corrector method (supplied with the IBM subroutine package as subroutine HPCG). The slope of these solutions gives a better fit to the data, particularly at the shorter scale lengths where the eddy diffusion coefficient is lower. The two variable K_H solution that we show would suggest that a residence time with respect to in situ scavenging of about 150 to 100 years is most appropriate. The implication is that much of the ^{210}Pb removal flux may be carried by mixing to a remote sink at the sea floor and that scavenging of this nuclide by particulate matter suspended in the water column may be of lesser importance.

The observation that $^{210}Pb/^{226}Ra$ ratios decrease as topographic boundaries are approached has been interpreted as evidence that scavenging at the sea floor is a major mechanism for removing ^{210}Pb from the deep sea. We have considered the possibility that this correlation may be caused by factors other than boundary scavenging. Possible "water-mass effects" were tested by a re-plotting of the data for 500 m depth intervals, and

the same correlation was observed for all depths. The apparent rate of ^{210}Pb scavenging at depth also appears unrelated to phytoplankton productivity in the overlying surface waters (22) and proximity to the northwest African source of windblown dust. It is not necessarily implied that rates of particle supply or production at the surface are unimportant in controlling the rates of deep scavenging for some elements, but these factors do not seem to be important in the particular case of ^{210}Pb.

The relatively rapid scavenging of ^{210}Pb at the sea floor that we have inferred from our data seems to require special explanation. A 4000 m water column lying above one square meter of sediment surface contains approximately 40 g of suspended solid. With a specific surface area of 20 m^2/g, typical of sediments (23), particles in suspension ought to be more "reactive" than the sea floor, at least on the basis of available surface area for reaction. It appears necessary then to postulate processes unique to the sea floor in order to account for removal of ^{210}Pb preferentially at that site, and it is suggested that co-precipitation of ^{210}Pb with manganese and iron oxides forming at the interface might be such a process. The extent to which manganese may be precipitating in the water column is not known, but it seems likely that the major site is at the sea floor. In anoxic basins it is known that manganese does precipitate in the water column just above the O_2-H_2S interface (24), and preliminary results from the Cariaco Trench (M. P. Bacon, unpublished data) strongly suggest an association of ^{210}Pb with manganese in this region. Chow and Patterson (25) have measured the distribution of lead in marine sediments and indicate a strong and widespread association of

lead and manganese.

Anomalously high concentrations of particulate iron have been reported in samples collected near the Mid-Atlantic ridge crest (26). Such anomalies could be the result of precipitation from the iron-rich solutions suggested to be leaking into the water column from volcanically active areas and leading to the formation of metalalliferous sediments (27). If this interpretation is correct, then the particulate ^{210}Pb profile at Me-32-18, near the Mid-Atlantic Ridge, which shows an anomalous maximum at about 3200 m, may provide further evidence that Pb-210 is rapidly co-precipitated by newly formed precipitates. An alternative explanation is that this maximum represents ^{226}Ra enrichment in the particulate matter sampled. In the absence of ^{226}Ra analyses for these samples, the question cannot be resolved. Further radiochemical analyses of particulate matter from this region are warranted.

5.4 Scavenging of ^{210}Po

The behavior of ^{210}Po in the deep sea is markedly different from that of ^{210}Pb with respect to its rate of association with suspended particles. Although the data are rather badly scattered, ^{210}Po shows a slight deficiency in the dissolved phase, averaging about 12%, and a corresponding enrichment in the particulate phase is found in nearly all of the samples (13). These observations can only be attributed to rapid in situ scavenging of ^{210}Po from solution. A value of about four years may be calculated for the mean residence time of ^{210}Po in the deep sea with respect to removal from solution.

It is of interest to examine whether this rapid transfer to particulate matter leads to any detectable net removal of ^{210}Po from the water column. In Table 9 are listed integrated vertical profile activities for total ^{210}Pb and ^{210}Po, obtained by summing dissolved and particulate analyses. These integrations have been performed over the entire water column. The mean difference is +1.2 dpm/cm^2 with a standard deviation of 2.0 dpm/cm^2. This difference is actually in the direction of ^{210}Po enrichment but is not significantly different from zero. The water column as a whole appears to be nearly in secular equilibrium. Although removal of ^{210}Po from solution is rapid, as indicated by its distribution between dissolved and particulate phases, the mean sinking velocity of ^{210}Po in particulate form is not large enough to maintain a total $^{210}Po/^{210}Pb$ disequilibrium throughout the water column. This lack of any significant total disequilibrium makes the sinking velocity essentially indeterminate. One can, however, rule out the possibility that significant amounts of ^{210}Po in the deep sea associate with particles having residence times very much less than four years.

6. Summary and conclusions

From material balance considerations it can be shown that ^{210}Pb in the surface mixed layer is supplied principally from the atmosphere, and for the tropical North Atlantic the rate of delivery is approximately 0.6 dpm/cm^2-y. The flux of ^{210}Po from the atmosphere is only about 10% of this value and is small compared with the rate of ^{210}Po turnover in the surface ocean. Residence times of ^{210}Pb and ^{210}Po in the mixed layer are about 2.5 y and 0.6 y, respectively. The population of particles bearing ^{210}Po in the mixed layer is replaced approximately 10 times per year. Interpretation of particle residence times in this region in terms of settling velocities is probably not appropriate. Removal of particles by filter-feeders and subsequent formation of fecal pellets, which sink very rapidly, may be as important as sinking of individual, small particles.

The residence times of ^{210}Pb and ^{210}Po in the mixed layer differ significantly from each other, and each is longer than the residence time of particulate matter. These observations suggest that specific chemical properties, which govern their rate of incorporation by plankton, control the removal of these nuclides. Their rate of removal is not appreciably limited by retention of particles in the mixed layer. Differences in chemical properties are also evident when recycling within the thermocline is considered. Of the ^{210}Po removed from the mixed layer, 50% or more is recycled at depths less than 400 m. Much smaller, and probably negligible, amounts of ^{210}Pb are recycled.

Within the deep ocean a pronounced $^{210}Pb/^{226}Ra$ disequilibrium is found at all stations, thus confirming the findings of Craig et al. (4). However, unless very rapid sinking of particles is invoked, our particulate ^{210}Pb profiles are not consistent with their model based on scavenging by suspended particles in the water column. We believe that the data are more consistent with a dual removal of ^{210}Pb both by scavenging and at the sediment-water interface. This conclusion is supported by observations that $^{210}Pb/^{226}Ra$ ratios decrease as the sea floor is approached. It is interesting to speculate that similar removal processes for a number of stable trace elements may contribute to the ridge enrichments that have often been observed and that have been interpreted as being due to volcanic or hydrothermal processes.

In contrast to ^{210}Pb, ^{210}Po rapidly associates with particulate matter in the deep ocean, its residence time in solution being on the order of four years. Both nuclides are highly "reactive" in the sense that they are subject to rapid removal from the oceans, but each follows a different pathway in being delivered to the sediments. A similar kind of separation on a short time scale may operate for ^{230}Th and ^{231}Pa (28).

Acknowledgements

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Figure Captions

Fig. 1 Station locations -- Atlantic.

Fig. 2a-d. Vertical profiles from the Atlantic. Open circles represent unfiltered samples for which a small correction was applied to the data (13). Results marked by parentheses were from questionable sampler (13). Radium profiles were estimated as described in the text.

Fig. 3. GEOSECS 226 ^{210}Pb profile. Dissolved and particulate analyses were combined to give totals (see text). Radium profile based on Broecker et al. (29).

Fig. 4. GEOSECS 320 profiles. The 3805 m results are uncertain because of leakage. Radium profile based on unpublished data of Y. Chung (cited in (9)).

Fig. 5. Ra versus Si for four Atlantic GEOSECS stations (W. S. Broecker et al., unpublished data). The straight lines are least-squares fits for stations west (1) and east (2) of the Mid-Atlantic Ridge.

Fig. 6. Vertical distribution of ^{210}Po-^{210}Pb disequilibrium in the upper layers of the tropical North Atlantic. All station numbers refer to F/S "Meteor" cruise 32.

Fig. 7. Particulate ^{210}Pb profile showing fit of equation (14). The best fit is shown by the 6800 m/y curve. Other curves result from substitution of other values for S with Po held constant. The two points in parentheses were disregarded in determining the best fit.

Fig. 8. Horizontal distribution of $^{210}Pb/^{226}Ra$ activity ratios. With

increasing distance from lateral boundaries, the ratio increases; i.e., the apparent ^{210}Pb residence time becomes longer. The curves are the best fits of equations (16) and (18). Samples within about 1000 m of the surface and bottom are omitted.

Table 1. Analytical data for
GEOSECS, Station 226, 30.6°N 170.6°E, 9-11 November 1973, 5590 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (μm/kg)	^{210}Pb Diss.	^{210}Pb Part.	^{210}Pb Tot.	^{210}Po Diss.	^{210}Po Part.	^{210}Po Tot.
				(dpm/100 kg)					
10	24.7	35.03		--	.23	--	--	2.7	--
40	24.7	35.03		--	.19	--	--	1.1	--
80	23.7	34.85		18.7	.09	18.8	13.4	1.3	14.7
150	16.2	34.73		19.8	.27	20.1	21.5	.5	22.0
250	14.4	34.58		14.2	.46	14.7	22.3	.4	22.7
350	13.2	34.43		14.0	.37	14.4	14.0	.5	14.5
452	10.46	34.292		12.3	.46	12.8	14.9	1.6	16.5
533	8.56	34.147		3.8	18.0	21.8	3.5	13.4	16.9
645	6.41	34.042		12.1	1.7	13.8	7.4	4.6	12.0
904	3.90	34.211		14.8	2.5	17.3	15.9	13.1	29.0
1192	--	34.403		15.4	4.0	19.4	17.8	5.5	23.0
1480	3.38	34.500		16.7	3.4	20.1	15.7	9.2	24.9
1542	--	34.495		13.3	4.2	17.5	3.4	21.0	24.4
2499	1.46	34.642		23.6	1.0	24.6	8.6	12.1	20.7
2999	1.28	34.665		1.5	28.3	29.8	2.0	30.0	32.0
3495	1.20	34.673		14.3	13.5	27.8	6.3	12.1	18.4
3980	--	34.686		9.6	12.5	22.1	6.2	15.5	21.7
4901	1.03	34.678		5.6	15.8	21.4	4.4	26.6	31.0
5434	.97	34.688		7.5	14.6	22.1	1.4	10.4	11.8

Samples at 350 m and above were collected by surface pump; samples at 452 m and below were collected in 270-l stainless-steel Gerard barrels.

Table 2. Analytical data for
GEOSECS, Station 320, 33.3°S 128.4°W, 24-26 April 1974, 4170 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (μm/kg)	^{210}Pb Diss. (dpm/100 kg)	^{210}Po Diss. (dpm/100 kg)
0	19.7	34.54		7.7 ± .6	4.0 ± .6
77	15.74	34.556		9.3 ± .6	5.5 ± .7
128	13.81	34.593		9.8 ± .7	10.4 ± .7
204	12.14	34.54		9.3 ± .7	10.9 ± .8
254	10.96	34.516		9.6 ± .7	9.9 ± .7
505	6.84	34.388		8.5 ± .6	7.5 ± .6
704	5.82	34.324		8.8 ± .6	10.2 ± .8
802	5.35	34.308		9.6 ± .7	9.7 ± .9
1002	4.32	34.328		11.1 ± .7	9.5 ± .8
1504	2.51	34.550		10.9 ± .7	10.7 ± .8
2054	1.888	34.645		17.8 ± 1.2	16.4 ± 1.7
2304	1.707	34.660		20.3 ± 1.2	19.1 ± 1.4
2605	1.54	34.663		19.4 ± 1.1	15.8 ± 1.4
3004	1.414	34.673		18.6 ± 1.1	18.6 ± 1.4
3502	1.30	34.686		19.1 ± 1.4	16.5 ± 2.3
3805	1.26	34.683		20.9 ± 3.2	15.3 ± 5.6
4107	1.16	34.691		17.8 ± 1.0	14.6 ± 1.2

All samples were collected in stainless-steel Gerard barrels.

TABLE 3

Ra-Si Relationships at Four Atlantic GEOSECS Stations.
Confidence limits are given at the 95% level.
Si (x) is in units of μm/kg, and
^{226}Ra (y) is in units of dpm/100kg.

Station	Slope	y-intercept
29	.144 ± .040	7.76 ± .72
40	.136 ± .043	8.07 ± .55
107	.217 ± .023	6.99 ± .87
115	.216 ± .023	6.88 ± .64

TABLE 4

Inventories of ^{226}Ra, ^{210}Pb and ^{210}Po in the surface layers of the North Equatorial Atlantic (Me-32-8, 12, 15, 18, 21, 22, 23, 27). Values are the arithmetic averages of all data points in the given depth intervals. Units are dpm/cm^2.

Depth interval (m)	A_1 ^{226}Ra	A_2^d $^{210}Pb(d)$	A_2^p $^{210}Pb(p)$	A_3^d $^{210}Po(d)$	A_3^p $^{210}Po(p)$
0-50	.38	.74	.039	.25	.067
0-100	.76	1.46	.063	.77	.126
50-300	1.96	3.26	.120	3.45	.249
50-400	2.82	4.32	.161	4.58	.337
100-300	1.60	2.52	.106	2.94	.190
100-400	2.46	3.57	.143	4.07	.280

Decay constants used: ^{210}Pb -- 0.0312 y^{-1}
^{210}Po -- 1.83 y^{-1}

TABLE 5

Results of box-model calculations for north equatorial Atlantic

Reservoir thickness (m)	I_a (dpm/cm^2-y)	Residence times in upper reservoir τ_{Pb}^d (y)	τ_{Po}^d (y)	τ_{Po}^P (y)	% re-cycled Pb	% re-cycled Po
0-50, 50-300	.51	1.4	.27	.08	8	41
0-50, 50-400	.51	1.4	.27	.08	9	55
0-100, 100-300	.61	2.3	.61	.11	5	67
0-100, 100-400	.61	2.3	.61	.11	6	79

TABLE 6

Integrated ^{226}Ra and Dissolved ^{210}Pb Activities For the Deep Water Column, Rates of ^{210}Pb Removal by Processes Other than Radioactive Decay, and Apparent Residence Times, τ.

Station	Depth range (m)	Dissolved ^{210}Pb (dpm/cm^2)	^{226}Ra (dpm/cm^2)	Removal Rate (dpm/cm^2-y)	τ (y)
Me-32-12	990-4880	17.4	45.9	.89	20
Me-32-15	700-5003(*)	19.8	49.9	.94	21
Me-32-18	666-3820	23.5	37.5	.44	54
Me-32-23	451-4940	45.4	61.1	.49	93
Me-32-27	887-4950	42.8	58.1	.48	90
Me-32-32	960-4440	31.1	47.7	.52	60
+ GEOPAC 201	984-4720	66.6	119.3	1.64	41
+ GEOPAC 314	977-4580	55.2	89.4	1.07	52

(+) Based on data from Applequist, 1975.

(*) The two bottom samples at this station were taken within the nepheloid layer, and the lower boundary is taken above this level. For all other stations, the lower boundary is set at the sea floor.

TABLE 7

Results of ^{210}Pb Sinking Velocity Calculations

Station	R (dpm/m^3-y)	S (m/y)	2σ limits (m/y)	No. of Observations	Spurious Points Discarded
Me-32-12	2.29	11,000	> 3,100	9	None
Me-32-15	2.18	--	>14,000	4	1813 m
Me-32-18	1.38	380	250-790	11	None
Me-32-23	1.09	--	> 6,600	11	None
Me-32-27	1.17	--	--	6	None
Me-32-32	1.49	6,800	> 2,600	8	1034,1477 m
(+) GEOPAC 201	4.40	2,200	1,500-3,900	9	None
(+) GEOPAC 314	2.96	1,600	970-4,200	13	None

(+) Based on data from Applequist, 1975.

TABLE 8

Rates of in situ ^{210}Pb scavenging calculated by two different methods

Station	From dissolved $^{210}Pb/^{226}Ra$ disequilibrium (as in Tables 6 and 7)		From $R = \lambda_2 P$ (ave)	
	$R(dpm/m^3\text{-}y)$	$\tau(y)$	$R(dpm/m^3\text{-}y)$	$\tau(y)$
Me-32-12	2.29	20	.23	200
Me-32-15	2.18	21	.094	490
Me-32-18	1.38	54	--	--
Me-32-23	1.09	93	.072	1400
Me-32-27	1.17	90	.11	960
Me-32-32	1.49	60	.066	1400

TABLE 9

Integrated total ^{210}Pb and ^{210}Po profile activities, surface to bottom. Units dpm/cm^2

Station	^{210}Pb	^{210}Po	^{210}Po-^{210}Pb
12	31	31	0
15	32	40	+8
18	34	34	0
23	52	53	+1
27	54	59	+5
32	45	39	-6
		Mean	+1±2

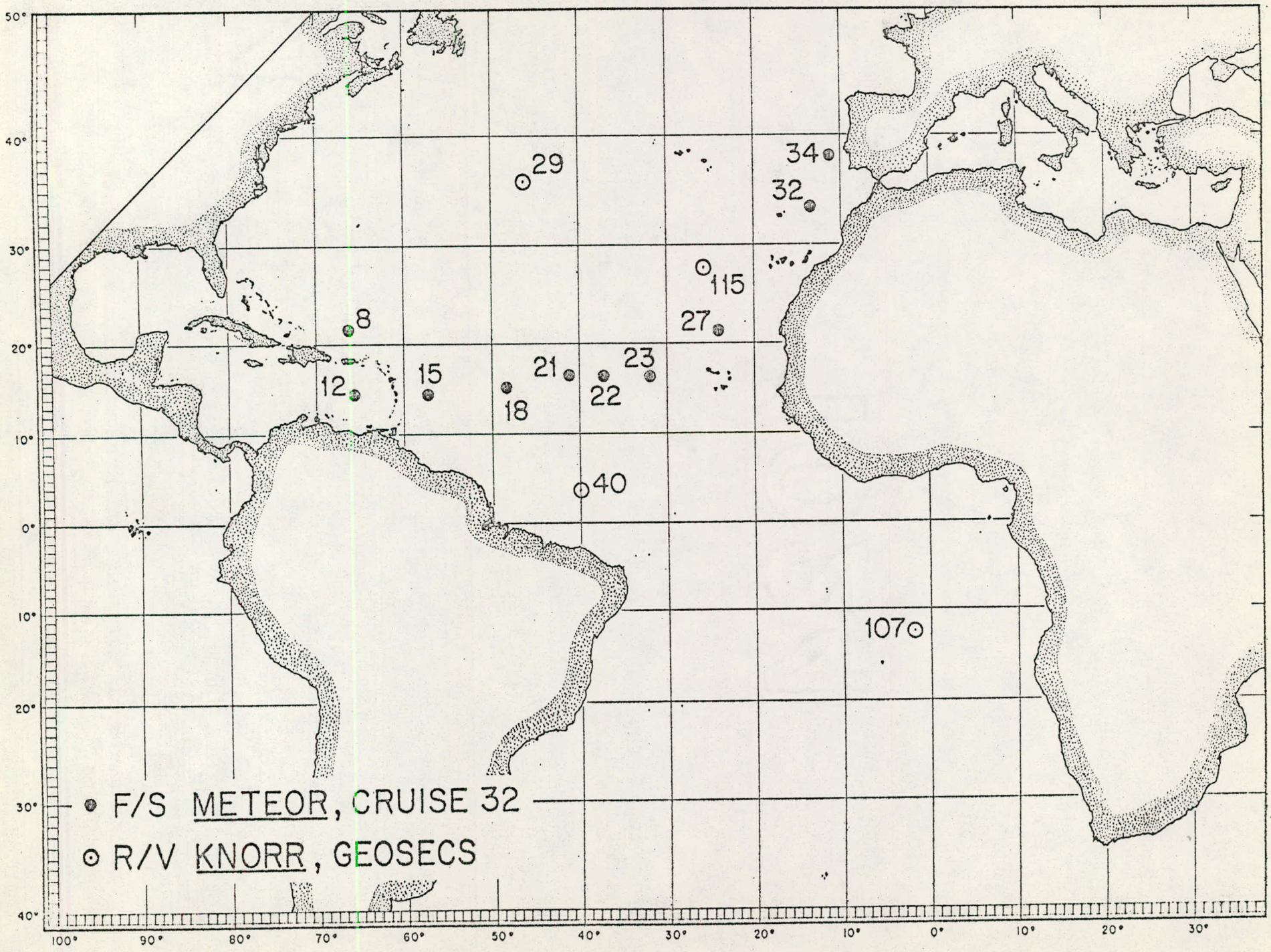
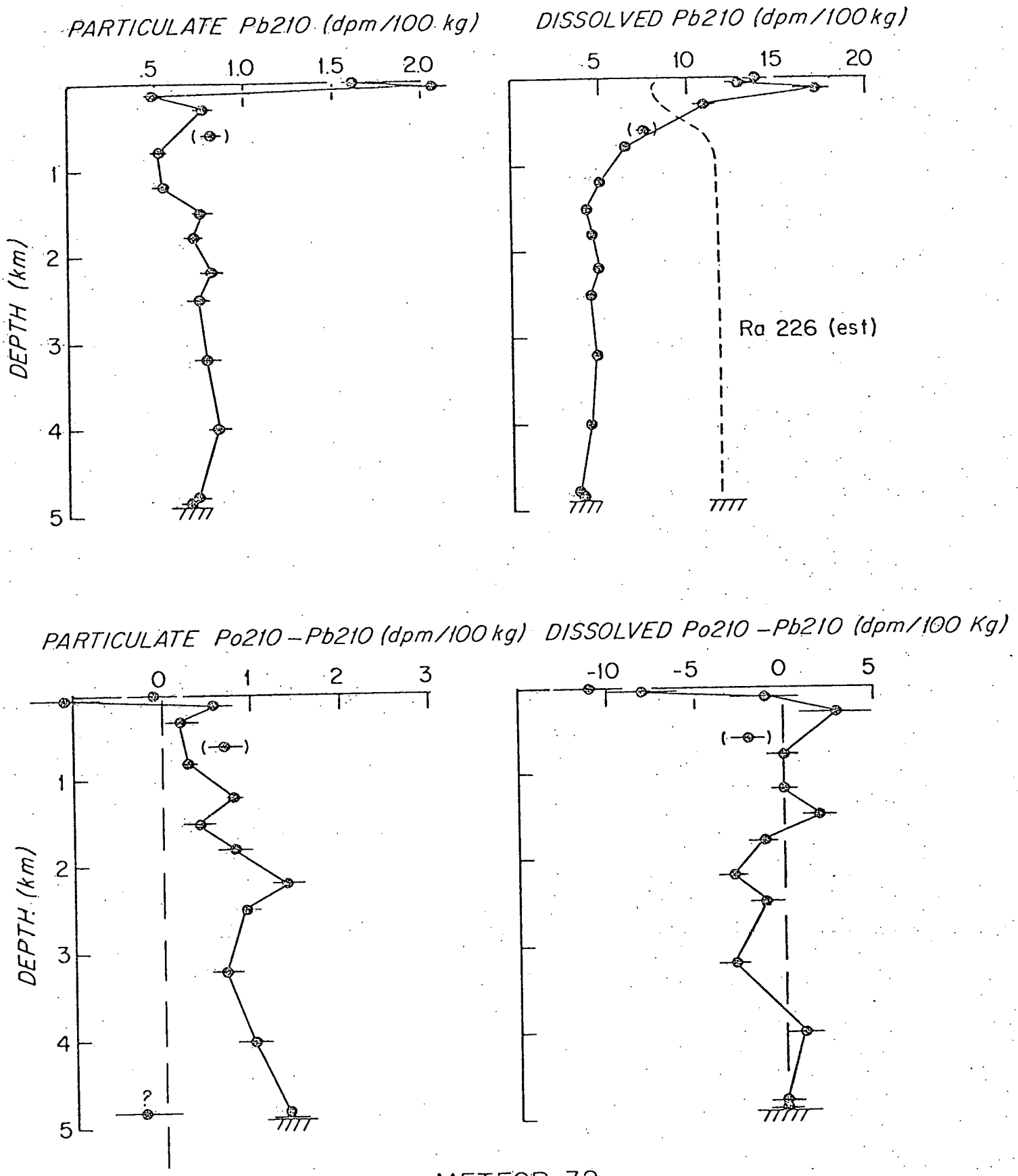
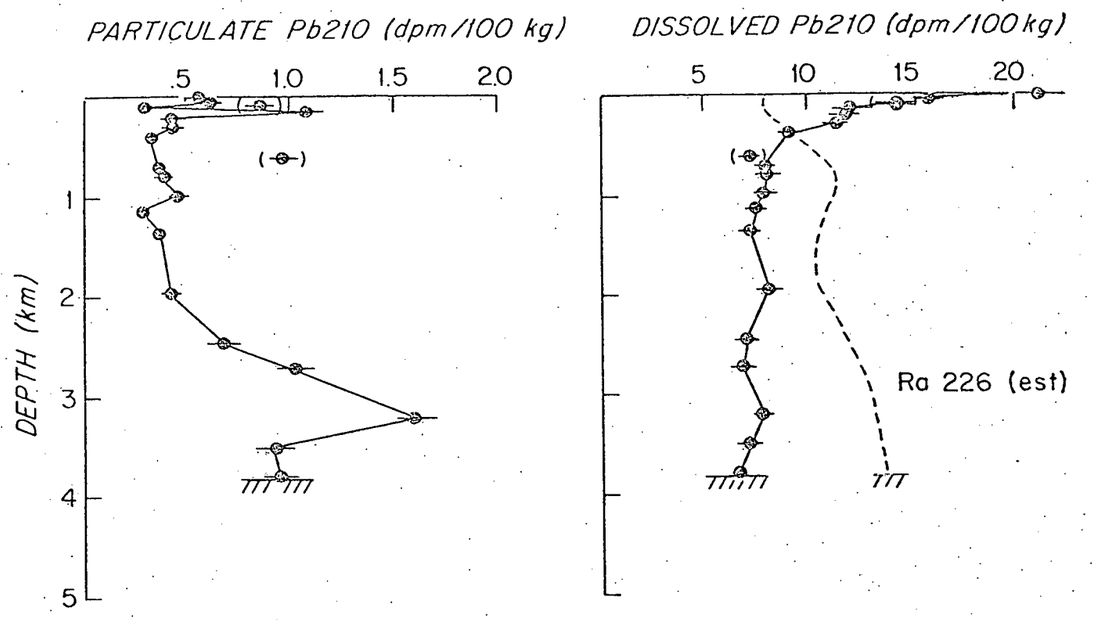

50°
40°
30°
20°
10°
0°
10°
20°
30°
40°
100°
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
10°
20°
30°
29
34
32
115
27
8
12
15
21
23
22
18
40
107
F/S METEOR, CRUISE 32
R/V KNORR, GEOSECS

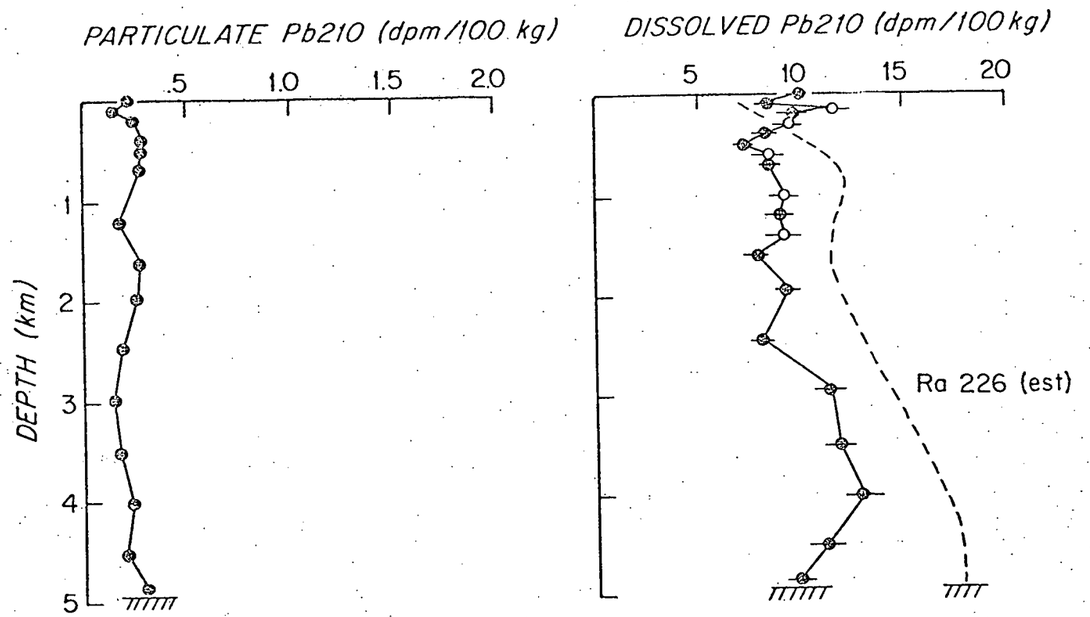
Figure 1

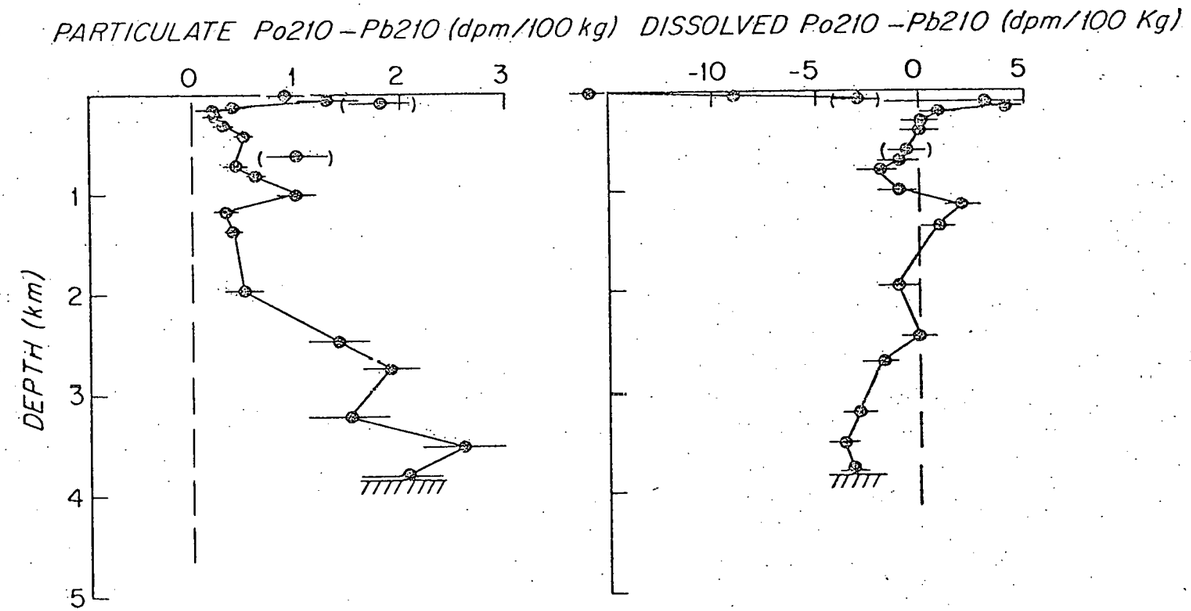


METEOR 32
STATION 12

Figure 2a

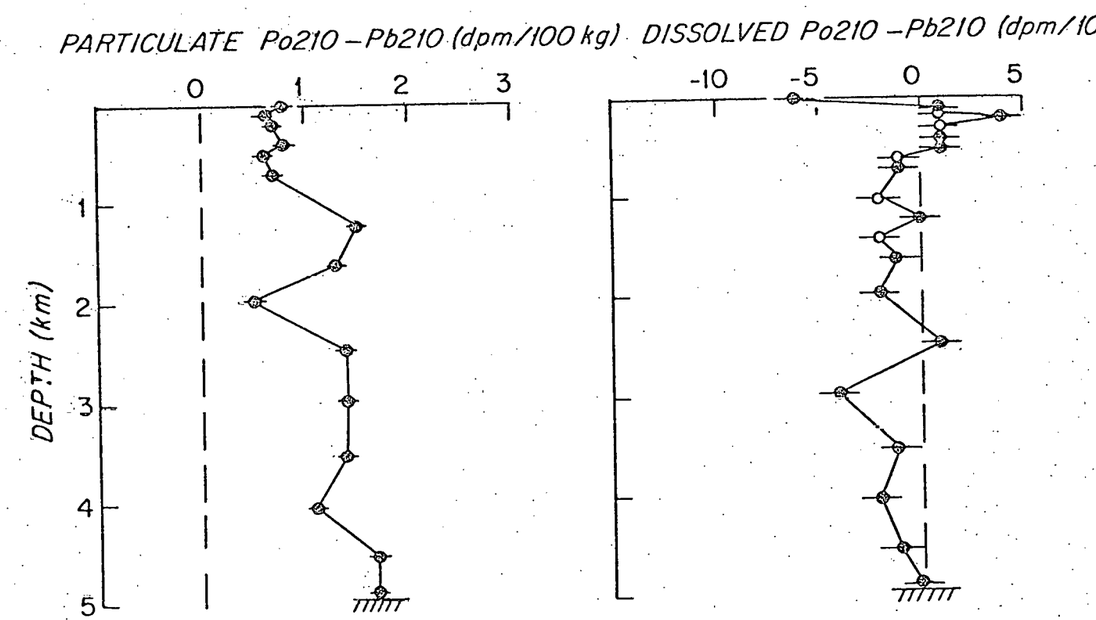






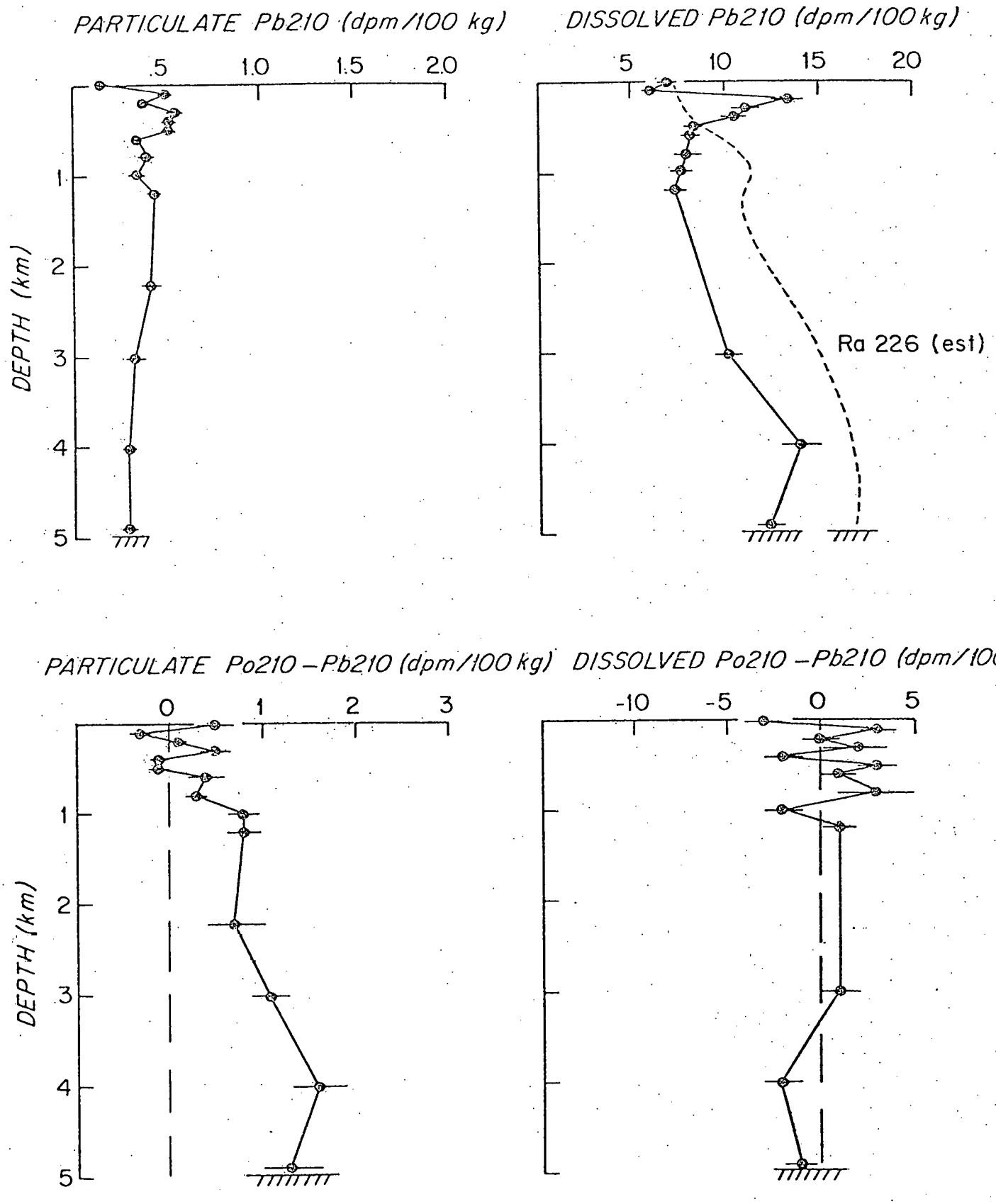
METEOR 32
STATION 18

Figure 2b



METEOR 32
STATION 23

Figure 2c



METEOR 32
STATION 27

Figure 2d

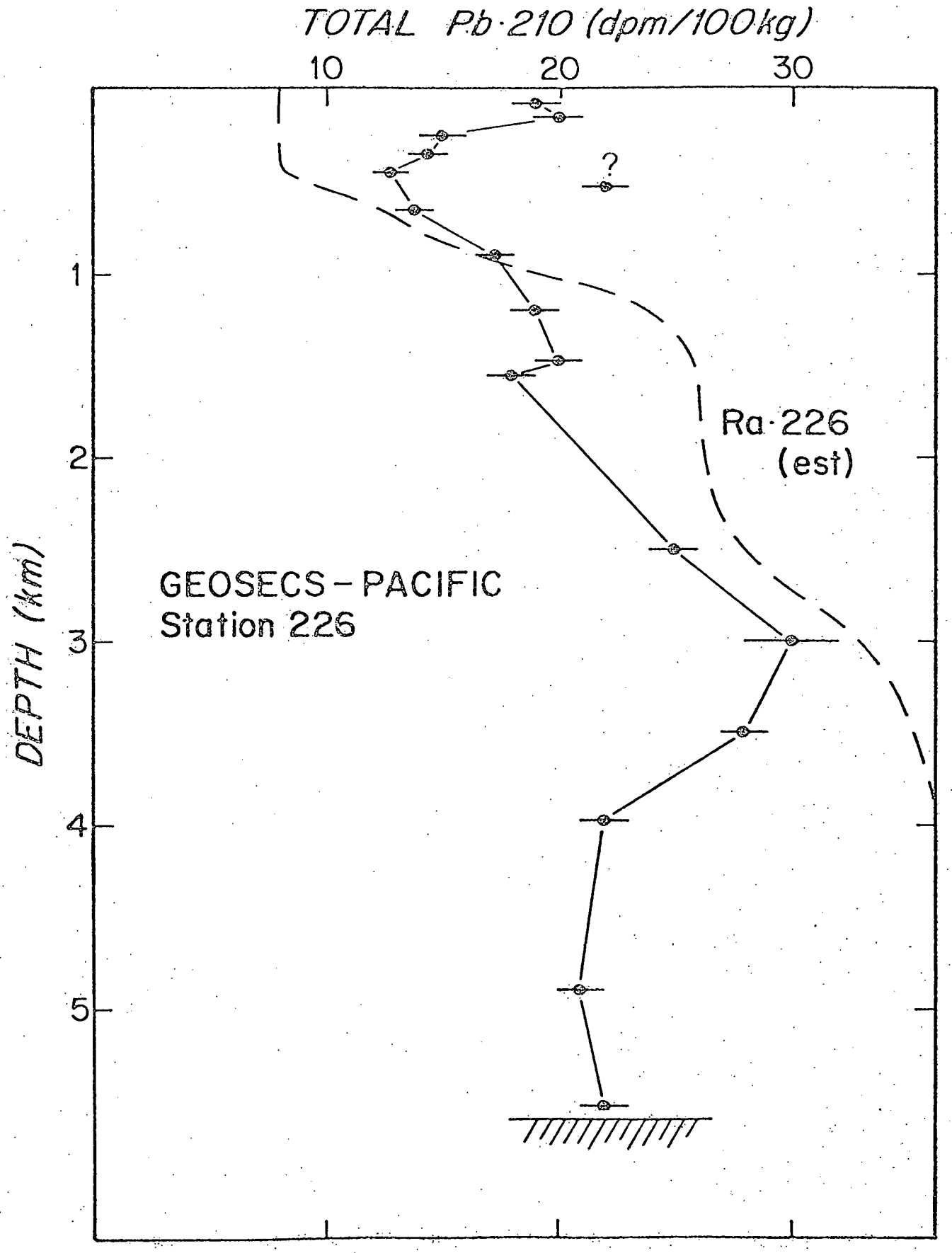

TOTAL Pb·210 (dpm/100kg)
10
20
30
?
1
2
3
4
5
DEPTH (km)
Ra·226
(est)
GEOSECS – PACIFIC
Station 226

Figure 3

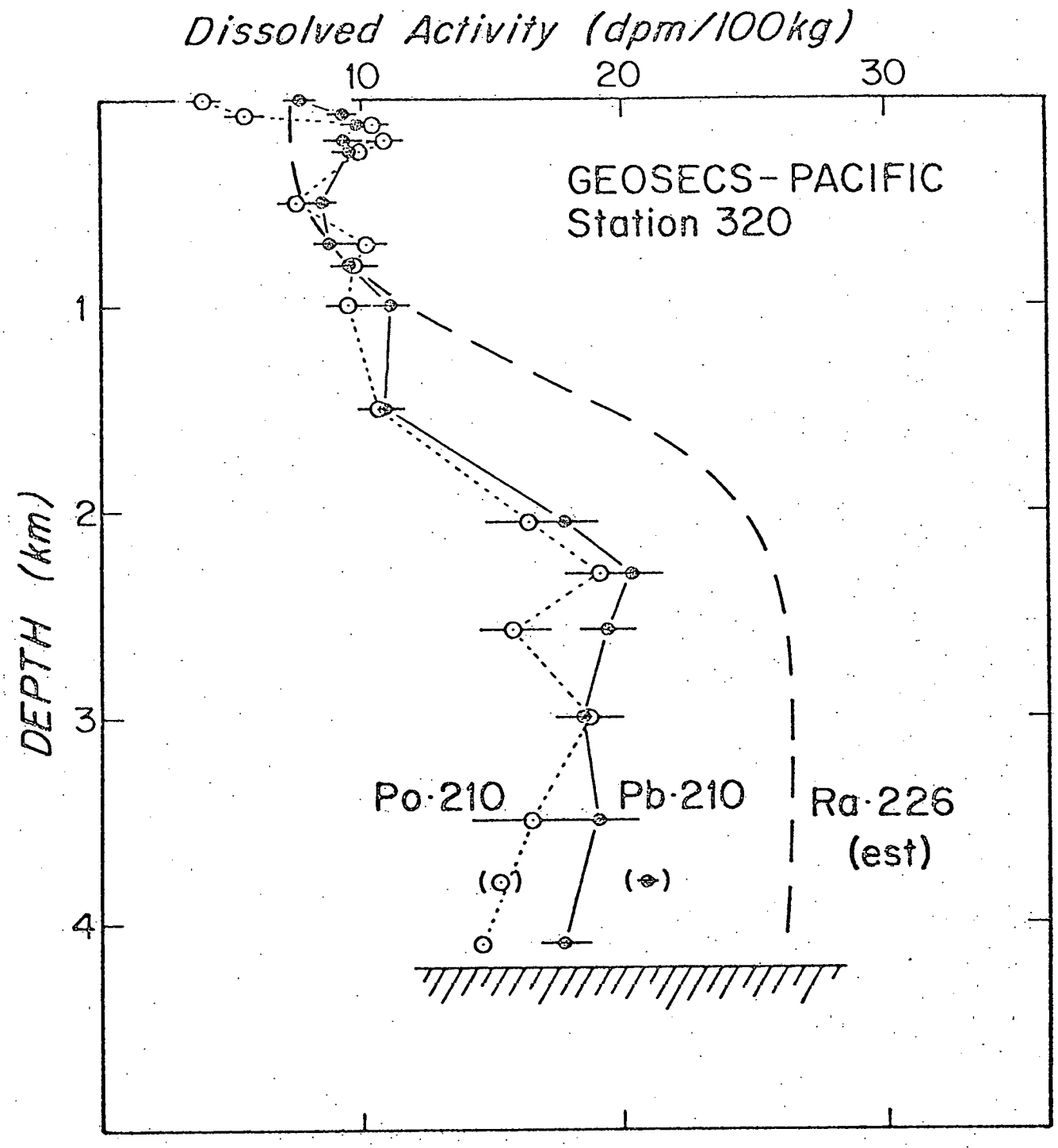

Dissolved Activity (dpm/100kg)
10
20
30
GEOSECS-PACIFIC
Station 320
1
2
3
4
DEPTH (km)
Po·210
Pb·210
Ra·226
(est)
(⊙)
(⊖)

Figure 4

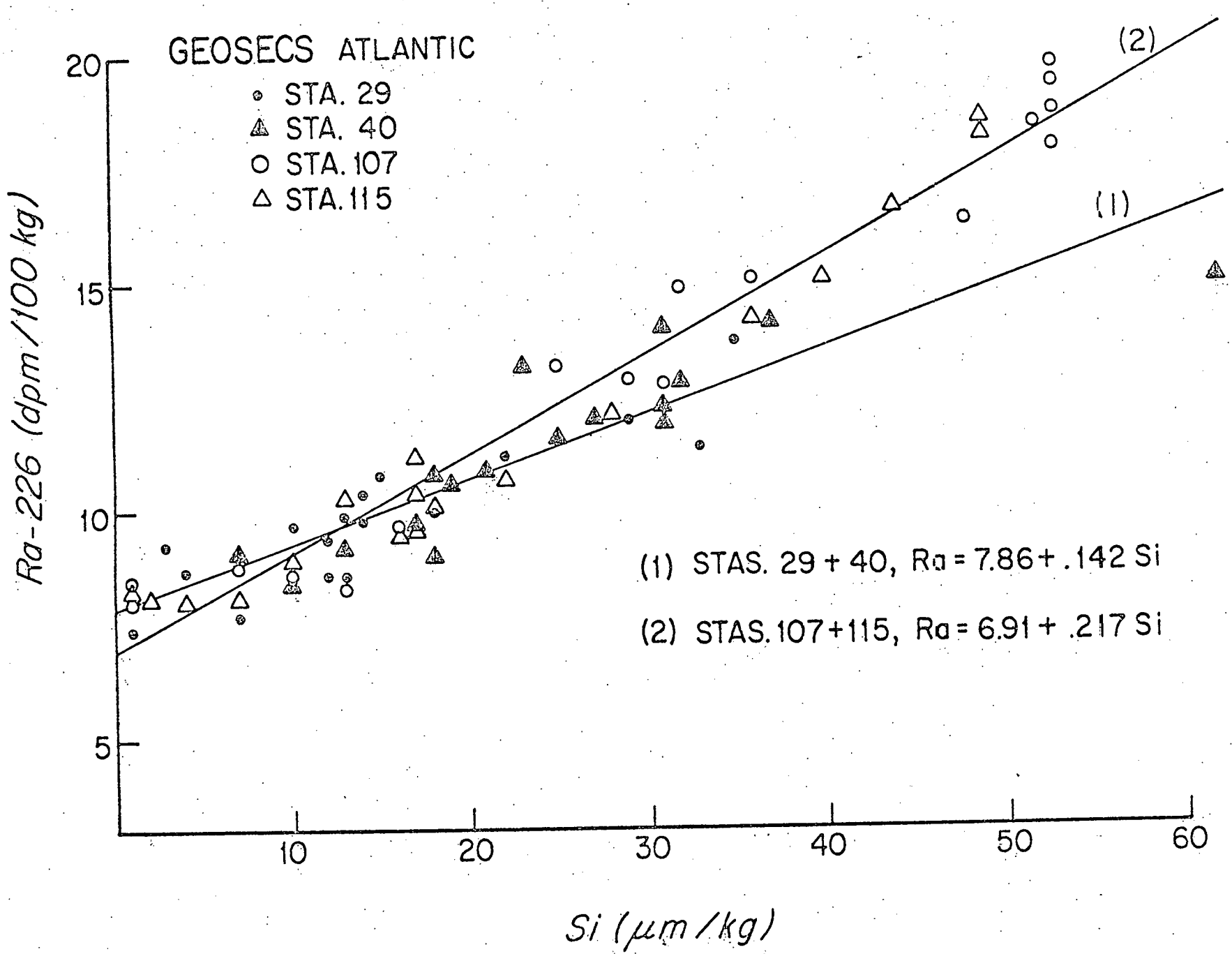

GEOSECS ATLANTIC
STA. 29
STA. 40
STA. 107
STA. 115
(1)
(2)
(1) STAS. 29 + 40, Ra = 7.86 + .142 Si
(2) STAS. 107 + 115, Ra = 6.91 + .217 Si
Ra-226 (dpm/100 kg)
Si (μm/kg)
20
15
10
5
10
20
30
40
50
60

Figure 5

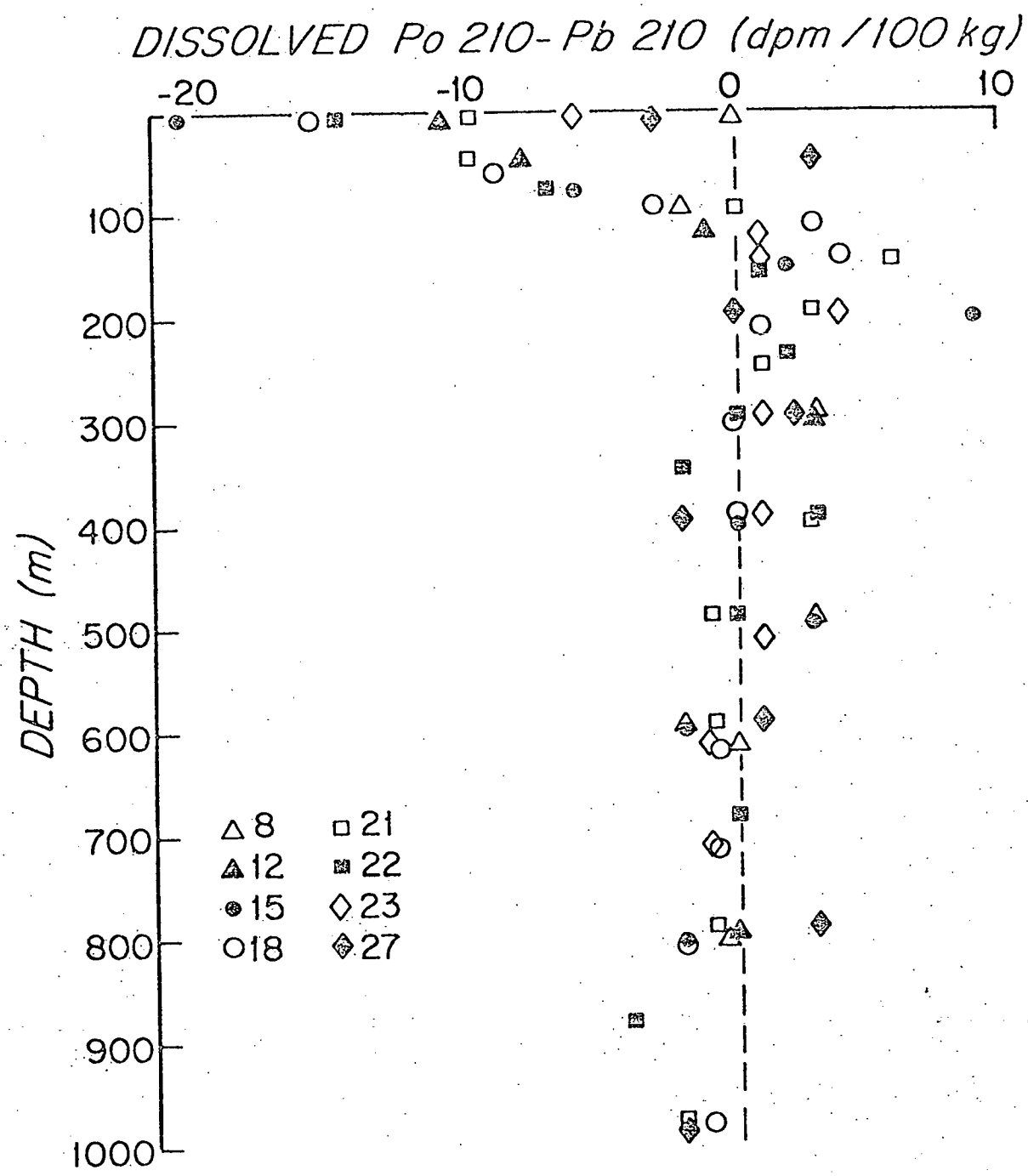

DISSOLVED Po 210- Pb 210 (dpm / 100 kg)
-20
-10
0
10
100
200
300
400
500
600
700
800
900
1000
DEPTH (m)
△ 8
▲ 12
● 15
○ 18
□ 21
■ 22
◇ 23
◆ 27

Figure 6

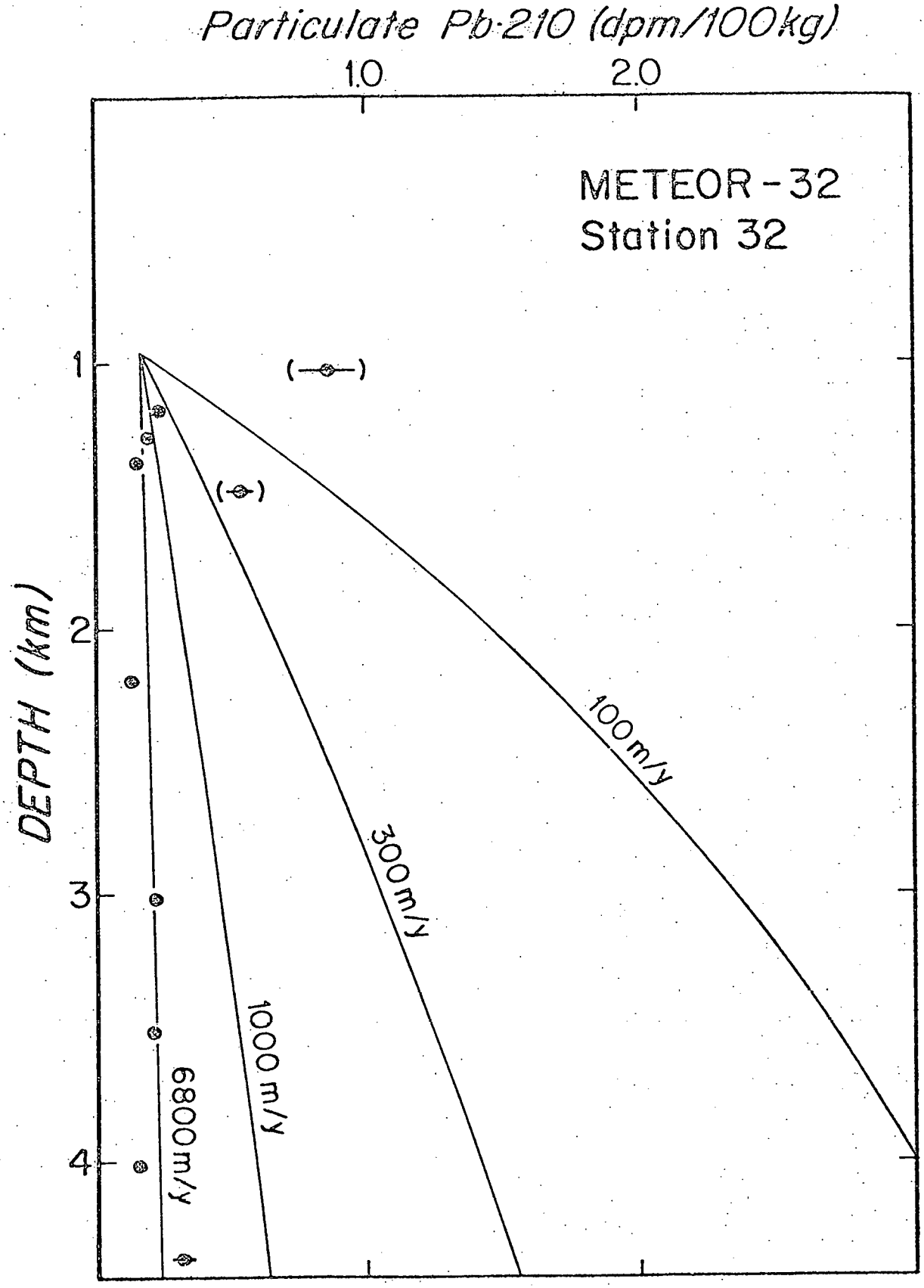

Particulate Pb-210 (dpm/100kg)
1.0
2.0
METEOR-32
Station 32
DEPTH (km)
1
2
3
4
100 m/y
300 m/y
1000 m/y
6800 m/y

Figure 7

Fig. 8

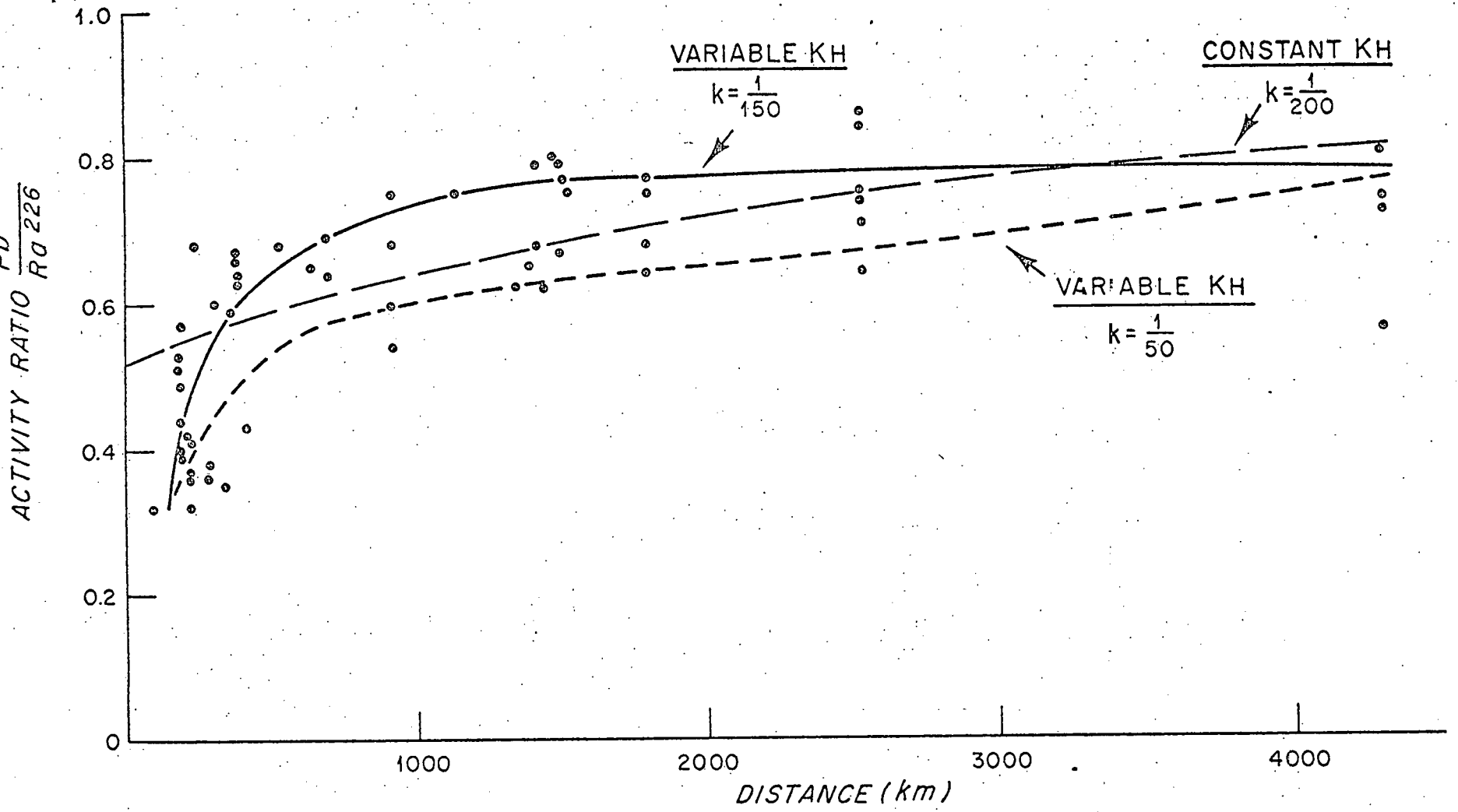


Figure 8

COO-3566-16

^{210}PB AND ^{210}PO RESULTS FROM F. S. "METEOR" CRUISE 32 IN THE NORTH ATLANTIC*

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*Contribution No. from the Woods Hole Oceanographic Institution

Abstract

The distribution of ^{210}Pb and ^{210}Po in dissolved (<0.4-micron) and particulate (>0.4-micron) phases has been measured at ten stations occupied during cruise 32 of F. S. "Meteor" in the tropical and eastern North Atlantic. Both radionuclides occur principally in the dissolved phase. Unsupported ^{210}Pb activities, maintained by flux from the atmosphere, are present in the surface mixed layer and penetrate into the thermocline to depths of about 500 m. Dissolved ^{210}Po is ordinarily present in the mixed layer at less than equilibrium concentrations, suggesting rapid biological removal of this nuclide. Particulate matter is enriched in ^{210}Po, with $^{210}Po/^{210}Pb$ activity ratios greater than 1.0, similar to those reported for phytoplankton. At depths of 100-300 m, ^{210}Po maxima occur, and unsupported ^{210}Po is frequently present, an observation that suggests rapid re-cycling within the thermocline.

Comparison of the ^{210}Pb distributions with those reported for ^{226}Ra at nearby GEOSECS stations has confirmed the widespread existence of a $^{210}Pb/^{226}Ra$ disequilibrium in the deep sea. Close to the bottom, profiles of ^{210}Pb and ^{226}Ra usually diverge, and ^{210}Pb concentrations frequently decrease with depth, suggesting a sink for ^{210}Pb near the seafloor. Particulate ^{210}Pb concentrations ordinarily show little systematic variation with depth. At depths greater than 1,000 m, dissolved ^{210}Po activities are, on the average, less than those of ^{210}Pb by 12%. A corresponding ^{210}Po enrichment in the particulate phase is found.

1. Introduction

The radionuclides ^{210}Pb and ^{210}Po occur naturally as members of the ^{238}U decay series. They are produced in the oceans by radioactive decay of their parent nuclides, and significant amounts of ^{210}Pb are also delivered to the sea surface following production by decay of ^{222}Rn and its short-lived daughters in the atmosphere. Because their rates of supply to the oceans can be accurately determined, and because of their suitable half-lives, ^{210}Pb and ^{210}Po serve as valuable tracers for studying the fate of certain "reactive" elements introduced to the sea.

Rama et al. (1961) were the first to measure ^{210}Pb concentrations in seawater, and they demonstrated that this nuclide is rapidly removed from the surface ocean, presumably as a result of biological processes. A simple box-model calculation led to a 2-year residence time for ^{210}Pb in the surface mixed layer, taken to be 100 m in thickness. A similar estimate was later given by Shannon et al. (1970), who also showed that ^{210}Po is removed even more rapidly. The shorter turnover time of ^{210}Po has been attributed to its preferential incorporation by plankton (Shannon et al. 1970; Turekian et al. 1974).

Recently Craig et al. (1973) reported that a pronounced $^{210}Pb/^{226}Ra$ disequilibrium exists in the deep sea, a result that has since been confirmed by a number of investigators (Tsunogai et al. 1974; Applequist 1975; Bacon 1975). This

discovery was important, because it was a clear demonstration that rapid removal processes are not confined to the biologically productive surface layer. Craig et al. (1973) explained the removal of ^{210}Pb in the deep ocean principally as the result of scavenging by sinking particulate matter.

This paper presents a number of detailed vertical profiles of ^{210}Pb and ^{210}Po activity in both dissolved and particulate forms. The samples were all obtained during cruise 32 of F. S. "Meteor" in November and December of 1973 (see Figure 1 for sampling locations), a cruise that was conducted in co-operation with the GEOSECS program (Geochemical Ocean Sections Study). The data presented here extend our understanding of the removal of these nuclides from the surface mixed layer and particularly their fate upon being transported to deeper levels. The extensive set of particulate-matter analyses allows the scavenging model of Craig et al. (1973) to be tested. Some of these aspects of the data are treated in further detail elsewhere (Bacon 1975; Bacon et al. 1976).

2. Methods

Water samples were collected with 270-l stainless-steel Gerard barrels and with pairs of 30-l PVC Niskin bottles spaced 5-10 meters apart on the wire. This latter arrangement was necessary on most stations because of winch failures that precluded use of the Gerard barrels at depths greater than 1500 m. Suspended particulate matter was sampled by pumping 40-100 liters of seawater through 142-mm diameter, 0.4-micron pore-size Nuclepore filters. For samples collected with the Gerard barrels, filtration was performed by pumping directly from the sampler. Because of space restrictions where the Niskin bottles were racked, when these samplers were used it was necessary first to transfer the samples to plastic drums before filtering. Filtration was ordinarily complete within one to three hours following collection. Total volumes of water filtered were measured with Hersey-Sparling water meters installed downstream from the filter holders. During filtration 20-l aliquots of filtered water were drawn into plastic vessels containing enough concentrated HCl to bring the pH within the range 1.5-2.0. The samples were then spiked with known amounts of ^{208}Po (several dpm) and stable Pb (a few mg) tracers and stored for later treatment. Mild suction was applied to the filters to remove excess water, and the filters were folded and sealed in plastic bags.

Analytical procedures are only briefly summarized here, since they have already been described in detail (Bacon 1975).

Seawater samples were treated by APDC chelate co-precipitation (Boyle and Edmond 1975) to concentrate the Pb and Po isotopes. Co-precipitation was followed by filtration with Millipore filters and wet combustion. Particulate matter samples were decomposed with mixtures of mineral acids. Samples were then dissolved in 2 N HCl, and Po was plated on silver discs (Flynn 1968) and counted with silicon surface-barrier detectors. The sample solutions were then stored for several months during which ^{210}Po was re-generated by decay of ^{210}Pb. A second plating and counting gave a measure of the ^{210}Pb present in the sample. Recovery of the added Pb carrier was determined by atomic absorption spectrophotometry.

3. Presentation of the data

Analytical results are listed in the Appendix, and vertical profiles are plotted in Figures 2a-j. Most of the samples were filtered at the time of collection, and for these samples both dissolved and particulate activities are reported. Definition of "dissolved" and "particulate" activity is made solely on the basis of retention or non-retention by the filters used. For samples that were not filtered, the results are listed as total activity, and these samples are marked

by the notation "NF" in the tables. Results from unfiltered samples have been included in the vertical profiles of dissolved activity, and for this purpose a correction, usually small, was derived by interpolation of the particulate profiles. Data points corrected in this way are indicated by use of a different symbol in the figures. All of the analytical results have been corrected for radioactive growth or decay to the date of collection, and they are given in units of disintegrations per minute per 100 kg sea water (dpm/100 kg). Polonium-210 results are plotted in most of the figures as activity differences relative to the parent ^{210}Pb. Positive values indicate the presence of "excess" ^{210}Po not supported by radioactive decay of the parent.

It may be seen in the vertical profiles that several of the particulate analyses are spuriously high, and in some of these cases the dissolved activities appear too low. This effect is most pronounced for the 1813-m sample from station 15. Many of these apparently bad samples from the Meteor cruise were collected with the same Gerard barrel (#18), and each of the samples taken with this particular sampler has been marked by an asterisk in the tables and by parentheses in the figures.

Radium analyses are being made at the University of Heidelberg, but the results are not yet available for inclusion in this report. Therefore ^{226}Ra distributions at the "Meteor" stations have been estimated from distributions at nearby GEOSECS stations (Figure 1) measured at the Lamont-Doherty Geological Observatory (W. S. Broecker et al. unpublished data). These estimates were based on Si profiles measured during the "Meteor" cruise and the close correlation existing between Ra and Si concentrations in oceanic profiles (Ku et al. 1970; Edmond 1970). Further details are given elsewhere (Bacon 1975; Bacon et al. 1976).

4. Distribution of ^{210}Pb

Ordinarily more than 90% of the ^{210}Pb in sea water occurs in the dissolved (<0.4 micron) phase. Activities near the surface are almost always in excess of ^{226}Ra activities, commonly by a factor of 1.5-2.5, a result that is in agreement with earlier work (Rama et al. 1961; Goldberg 1963; Craig et al. 1973, Applequist 1975). This ^{210}Pb excess is maintained by delivery to the sea surface of unsupported ^{210}Pb produced in the atmosphere by ^{222}Rn decay (Rama et al. 1961).

In some cases the largest ^{210}Pb excess is found at the immediate surface (stations 15, 18, 21, 22), but it is just as common for sub-surface maxima to occur in the 100-200 m depth range (stations 8, 12, 23, 27, 32).

Below the surface or near-surface maxima, ^{210}Pb concentrations show a fairly smooth decrease through the thermocline, and the effect of the atmospheric source appears to fall off rapidly. At depths of approximately 500 m, ^{210}Pb and ^{226}Ra profiles cross, and below these depths ^{210}Pb is invariably depleted all the way to the bottom. It is interesting to note that, for all of the Me-32 profiles between 14° and 22°N (stations 8-27), the point of crossing occurs at nearly the same potential density surface (σ_θ=27.0 ±0.1). This surface occurs slightly above the O_2-minimum in this region.

At mid-depths there is a tendency for ^{210}Pb profiles to parallel those of ^{226}Ra, and the two profiles often show a common maximum at about 1,000 m (stations 18, 21, 22, 23). This similarity is to be expected if the principal source of ^{210}Pb is the decay of ^{226}Ra and if ^{210}Pb removal processes are not confined to a particular level in the deep water column. Curious exceptions to this general behavior are noted in three of the profiles (stations 18, 22, 23) at a depth of about 2,000 m, where ^{210}Pb maxima (in each case defined by only a single point) coincide with ^{226}Ra minima.

Close to the bottom, ^{210}Pb and ^{226}Ra profiles always show some tendency to diverge, with ^{210}Pb concentrations decreasing toward the

bottom and ^{226}Ra concentrations remaining constant or increasing slightly. A broad ^{210}Pb maximum frequently results. This effect is least pronounced, but still detectable, at station 12 in the Caribbean (Venezuelan Basin), where other properties show the water column to be well-mixed vertically below sill depth (1960 m). The observation that ^{210}Pb and ^{226}Ra profiles diverge toward the bottom has been made previously (Craig et al. 1973); its confirmation here is regarded as highly significant, because it implies that ^{210}Pb removal processes do not operate uniformly with depth in this region. These implications are further discussed in another paper (Bacon et al. 1976).

Particulate ^{210}Pb concentrations are ordinarily in the range 0.2-0.5 dpm/100 kg and show little systematic variation with depth. Uncommonly high surface values were measured at station 12 (1.7 dpm/100 kg) and 21 (1.1 dpm/100 kg), and deep water values at station 12 in the Caribbean appear to be somewhat higher (0.7-0.8 dpm/100 kg) than those typical of the other Atlantic stations.

An exceptional profile occurs at station 18, where a well-defined particulate ^{210}Pb maximum occurs at about 3200 m. This station was located approximately 250 km west of the Mid-Atlantic Ridge crest, and it is suggested (Bacon et al 1976) that the anomalous distribution observed here may be related to processes unique to this location. A very similar particulate ^{210}Pb profile was obtained by Somayajulu and Craig (1973) at GEOSECS 48, a station similarly situated with respect to the ridge axis.

Unusually high particulate ^{210}Pb concentrations are also found close to the bottom at station 15 and are possibly an indication of high rates of scavenging within the near-bottom nepheloid layer. Relatively low values in the dissolved ^{210}Pb profile are also seen at the same depths. The existence of a nepheloid layer at this station could not be confirmed by observation, but the distributions of light scattering and total suspended load in the 11°N section given by Betzer et al. (1974) show that a nepheloid layer should be present in this region.

5. Distribution of ^{210}Po

With the exception of station 8, dissolved ^{210}Po shows a deficiency at the surface, the extreme case being station 15, where dissolved ^{210}Po was virtually undetectable at the surface. This $^{210}Po/^{210}Pb$ disequilibrium has been noted previously, and it has been ascribed to the preferential removal of ^{210}Po by plankton (Shannon et al. 1970; Turekian et al. 1974).

Below the mixed layer, ^{210}Po concentrations increase rapidly and usually pass through maxima at depths of 100-300 m. Within these maxima ^{210}Po often occurs in excess of ^{210}Pb, an effect which has not been reported in previous literature. The existence of unsupported ^{210}Po implies the operation of processes that rapidly supply ^{210}Po to this layer of the water column. This evidence for re-cycling of ^{210}Po within the thermocline is further discussed by Bacon et al. (1976).

Within the deep water ^{210}Po concentrations show considerable scatter, and it is not possible to recognize any features that are

reproduced from one profile to the next. Histograms of $^{210}Po/^{210}Pb$ activity ratios below 1,000 m are shown in Figure 3, and statistics are summarized in Table 1. On the average, dissolved ^{210}Po activities are less than those of ^{210}Pb by about 12%, a difference that is significant at the 95% confidence level. There do not appear to be significant variations in the activity ratio with depth, but a weak suggestion of a minimum exists in the means for 1,000-m intervals.

In the particulate phase ^{210}Po nearly always exists in excess of ^{210}Pb, an observation that is consistent with the notion that deficiencies in the dissolved phase are maintained by interaction with particulate matter. At the surface, particulate $^{210}Po/^{210}Pb$ activity ratios range from 1.0-5.2, similar to the range observed for phytoplankton (Shannon et al. 1970). Particulate ^{210}Po excesses are maintained throughout the deep water and on the average are just sufficient to balance dissolved ^{210}Po deficiencies. Total $^{210}Po/^{210}Pb$ activity ratios are not significantly different from 1.0.

6. Conclusions

Data presented in this paper confirm earlier observations that ^{210}Pb is generally enriched with respect to its radioactive parent ^{226}Ra in surface water and is depleted throughout the deep water column. Particulate ^{210}Pb profiles, however, show little systematic variation with depth and do not follow the pattern of increasing concentration with depth predicted by the model of Craig et al. (1973). Lead-210 concentrations often decrease with depth near the bottom, suggesting that the seafloor is an important ^{210}Pb sink (Bacon 1975; Bacon et al. 1976).

Polonium-210 shows evidence of being rapidly removed from surface seawater, as pointed out previously by others. A systematic occurrence of unsupported ^{210}Po has been discovered at depths of 100-300 m throughout the tropical North Atlantic, indicating rapid, shallow re-cycling of this nuclide. At greater depths there is a continuous transfer of ^{210}Po from the dissolved to the particulate form. This transfer is evidenced by a ^{210}Po depletion in the dissolved phase and a corresponding enrichment in the particulate phase.

Acknowledgements

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TABLE 1

Summary of $^{210}Po/^{210}Pb$ Activity Ratios Below 1,000 m For All Stations. Confidence limits for the mean were calculated at the 95% level.

Depth(m)	Median	Mean
Dissolved		
> 1,000 (all)	.87	.88 ± .05
1,000 - 2,000	.91	.95 ± .08
2,000 - 3,000	.80	.82 ± .14
3,000 - 4,000	.81	.81 ± .17
> 4,000	.89	.90 ± .07
Total		
> 1,000 (all)	.98	1.06 ± .06
1,000 - 2,000	1.00	1.07 ± .08
2,000 - 3,000	.98	1.02 ± .18
3,000 - 4,000	.92	1.03 ± .18
> 4,000	.99	1.11 ± .19

Figure captions

1. Sampling locations for ^{210}Pb and ^{210}Po during cruise 32 of F. S. "Meteor". Also shown are locations of R. V. "Knorr" GEOSECS stations upon which estimated ^{226}Ra profiles are based.

2a-j. Vertical profiles of ^{210}Pb, ^{210}Po-^{210}Pb activity difference and estimated ^{226}Ra for F. S. "Meteor" cruise 32. Corrected results for unfiltered samples are plotted as open circles, and results from questionable sampler are marked by parentheses.

3. Frequency distributions of $^{210}Po/^{210}Pb$ activity ratios at depths below 1,000 m for all stations.

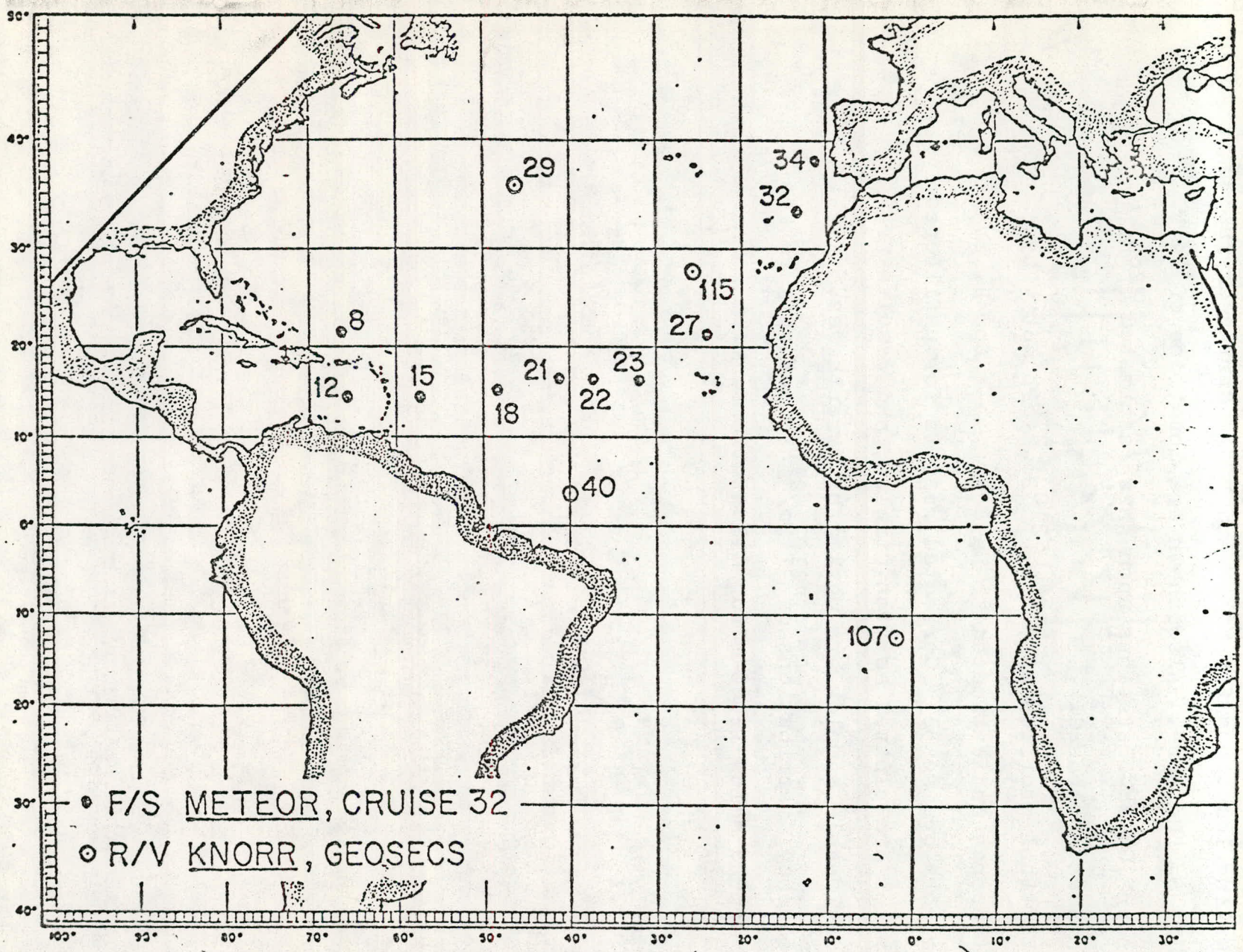
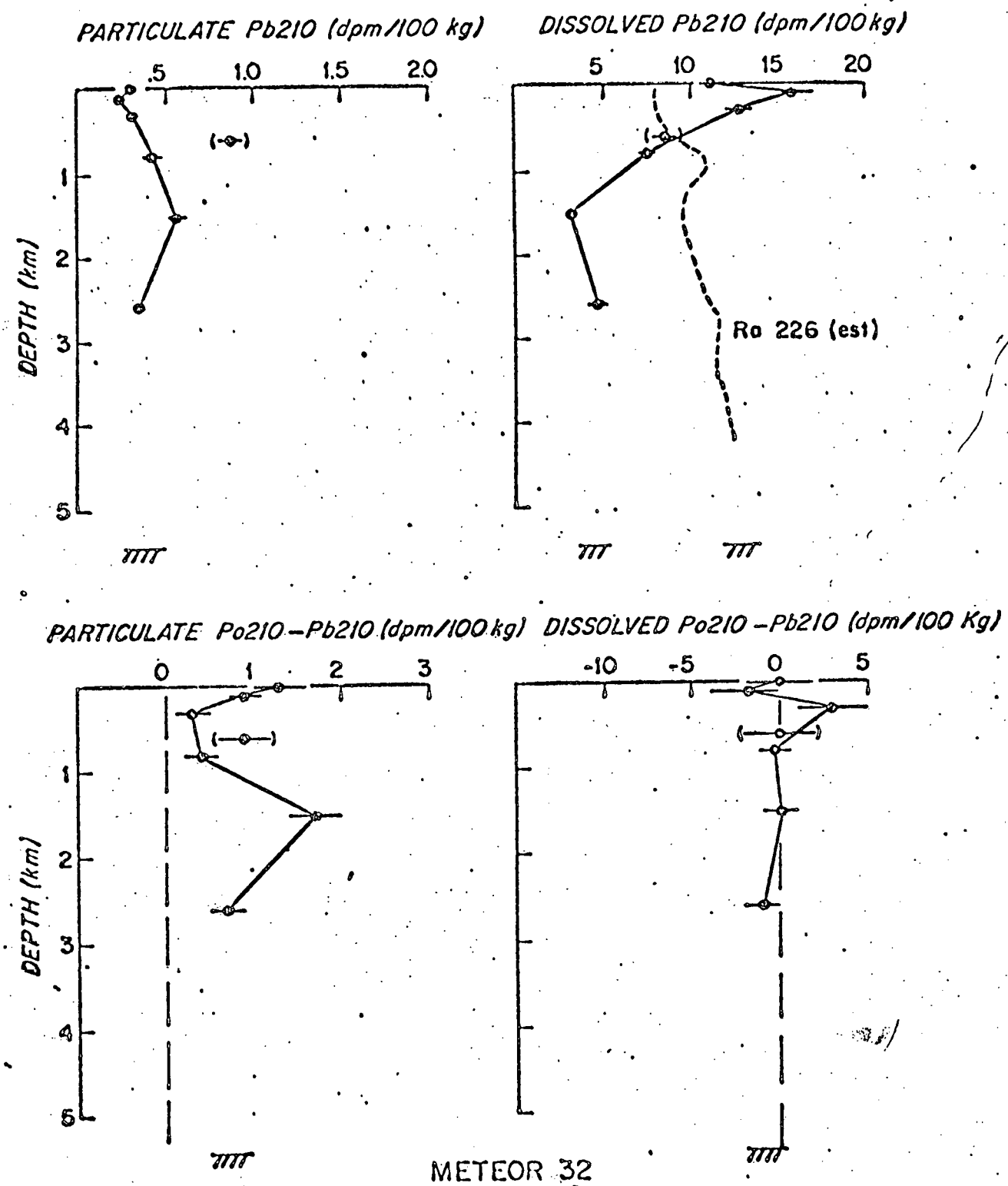
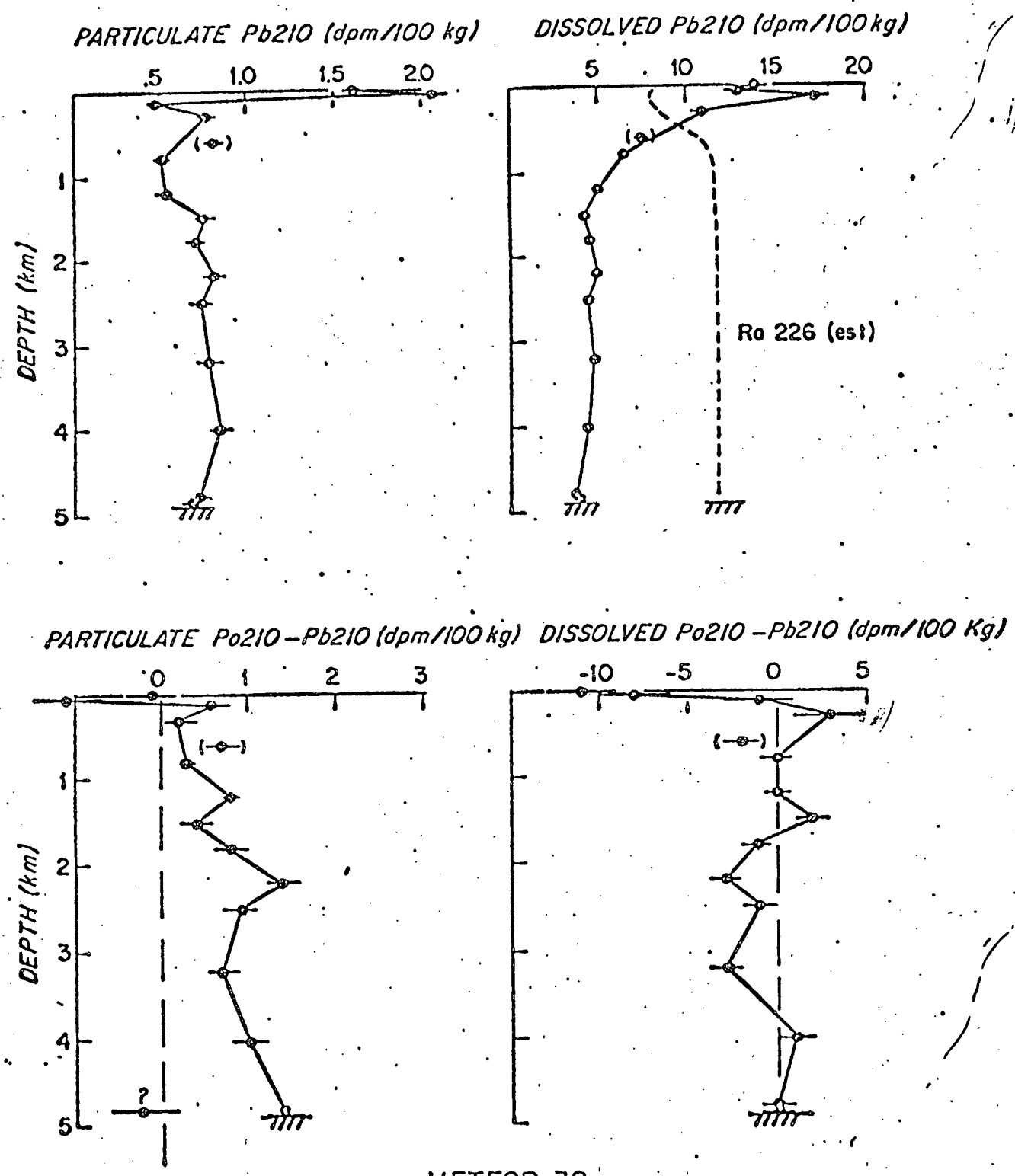

29
34
32
115
27
8
12
15
21
23
22
18
40
107
F/S METEOR, CRUISE 32
R/V KNORR, GEOSECS

Fig.



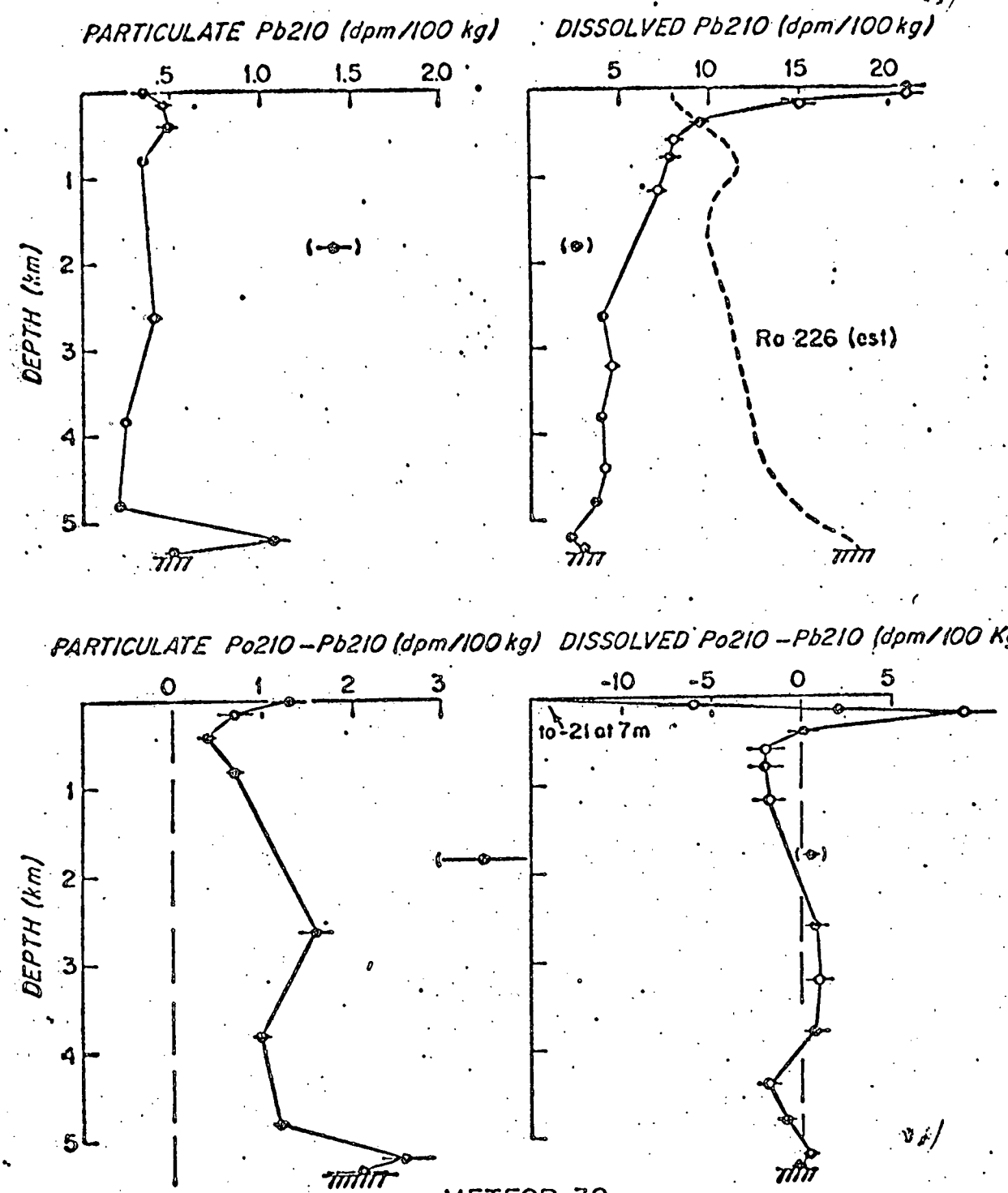
METEOR 32
STATION 8

Fig. 2a



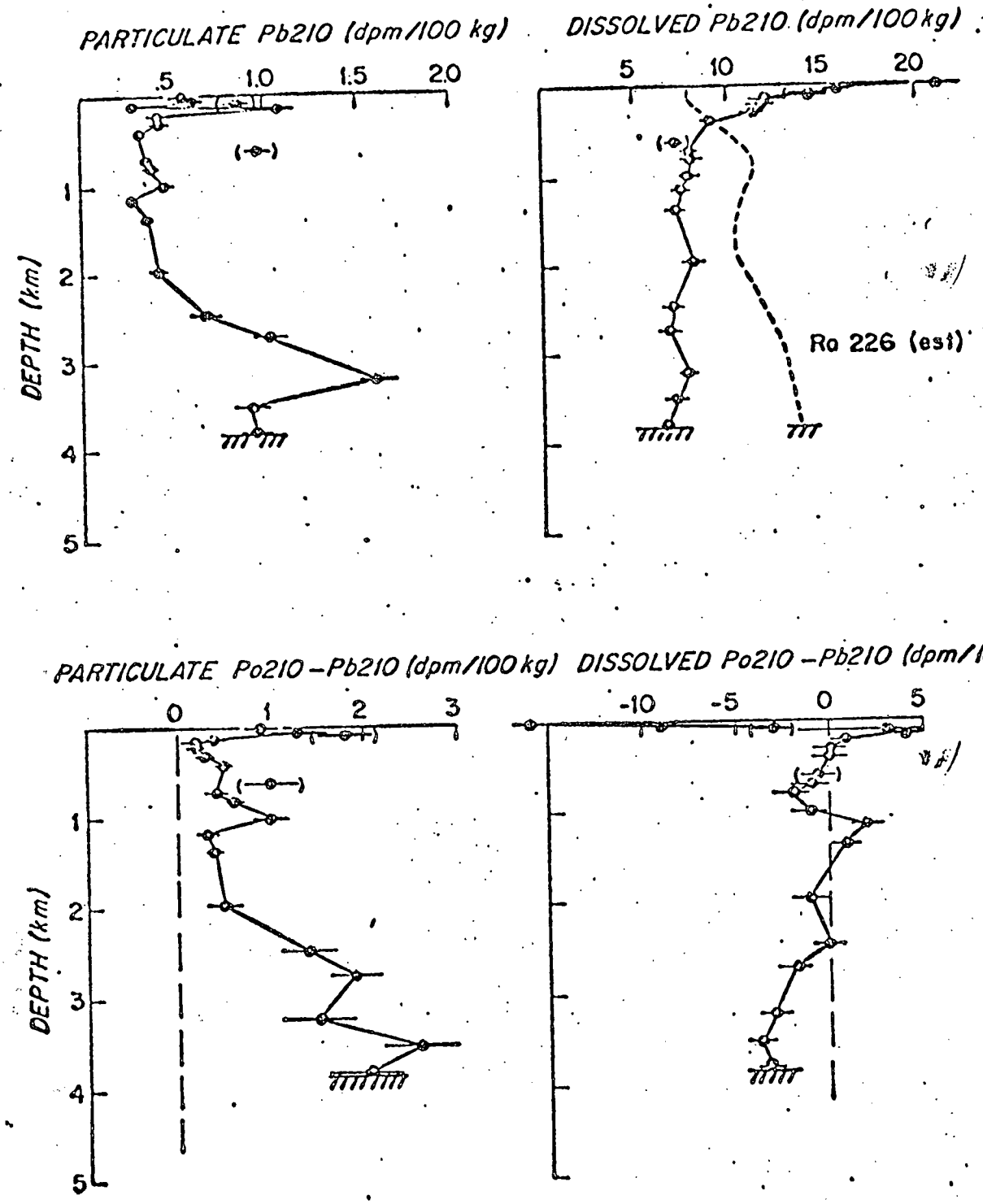
METEOR 32
STATION 12

Fig. 2b



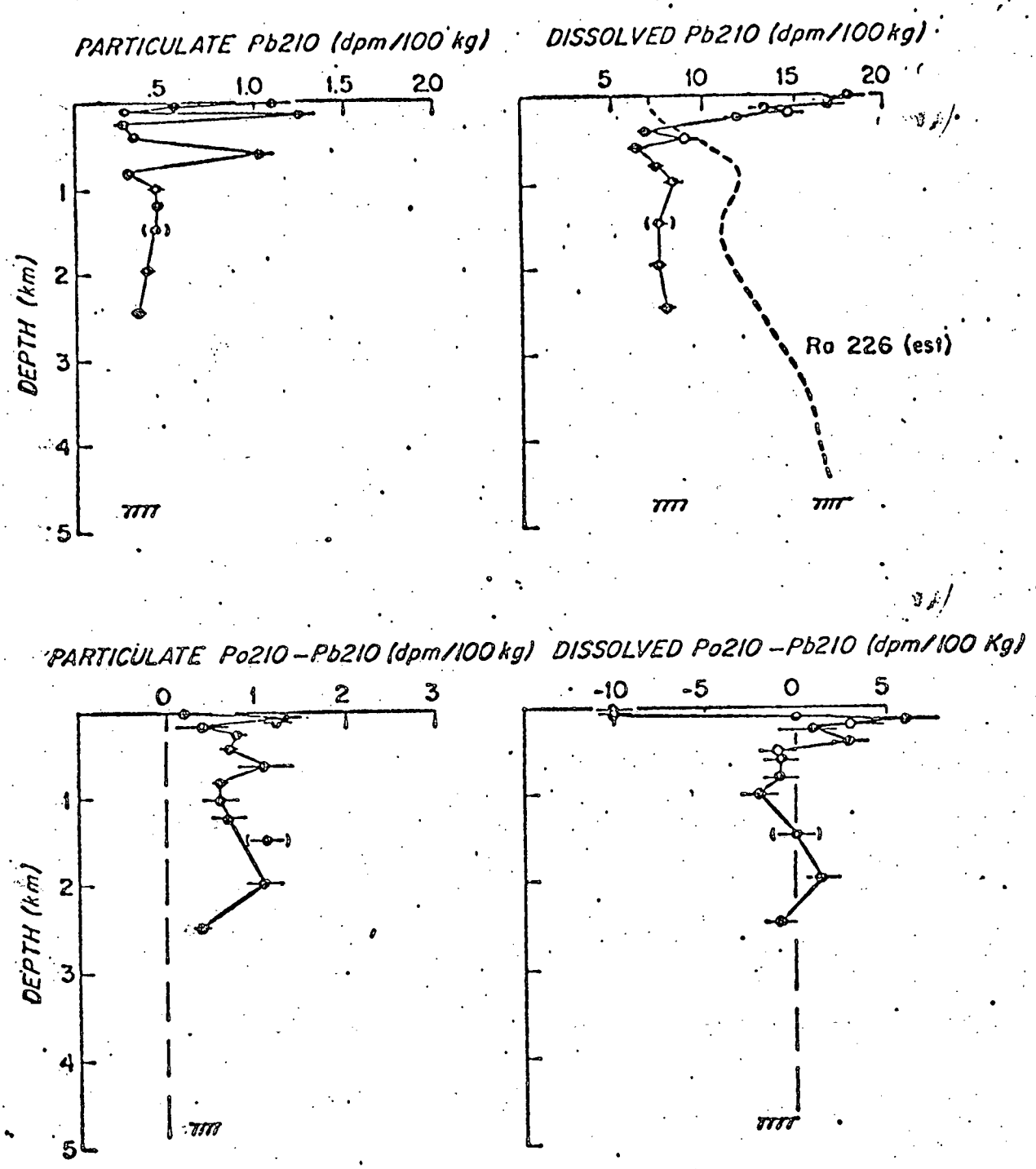
METEOR 32
STATION 15

Fig. 2c



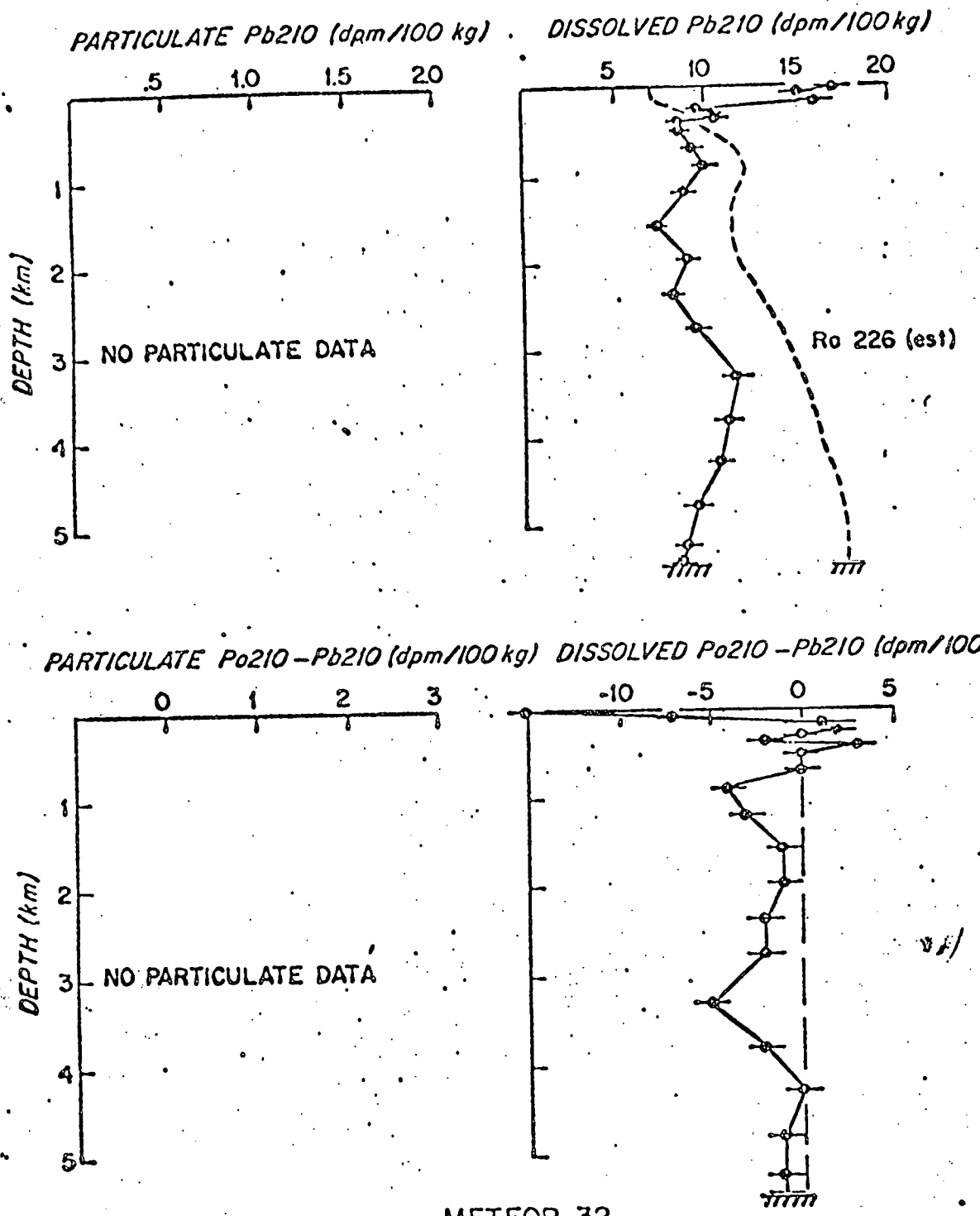
METEOR 32
STATION 18

Fig. 2a



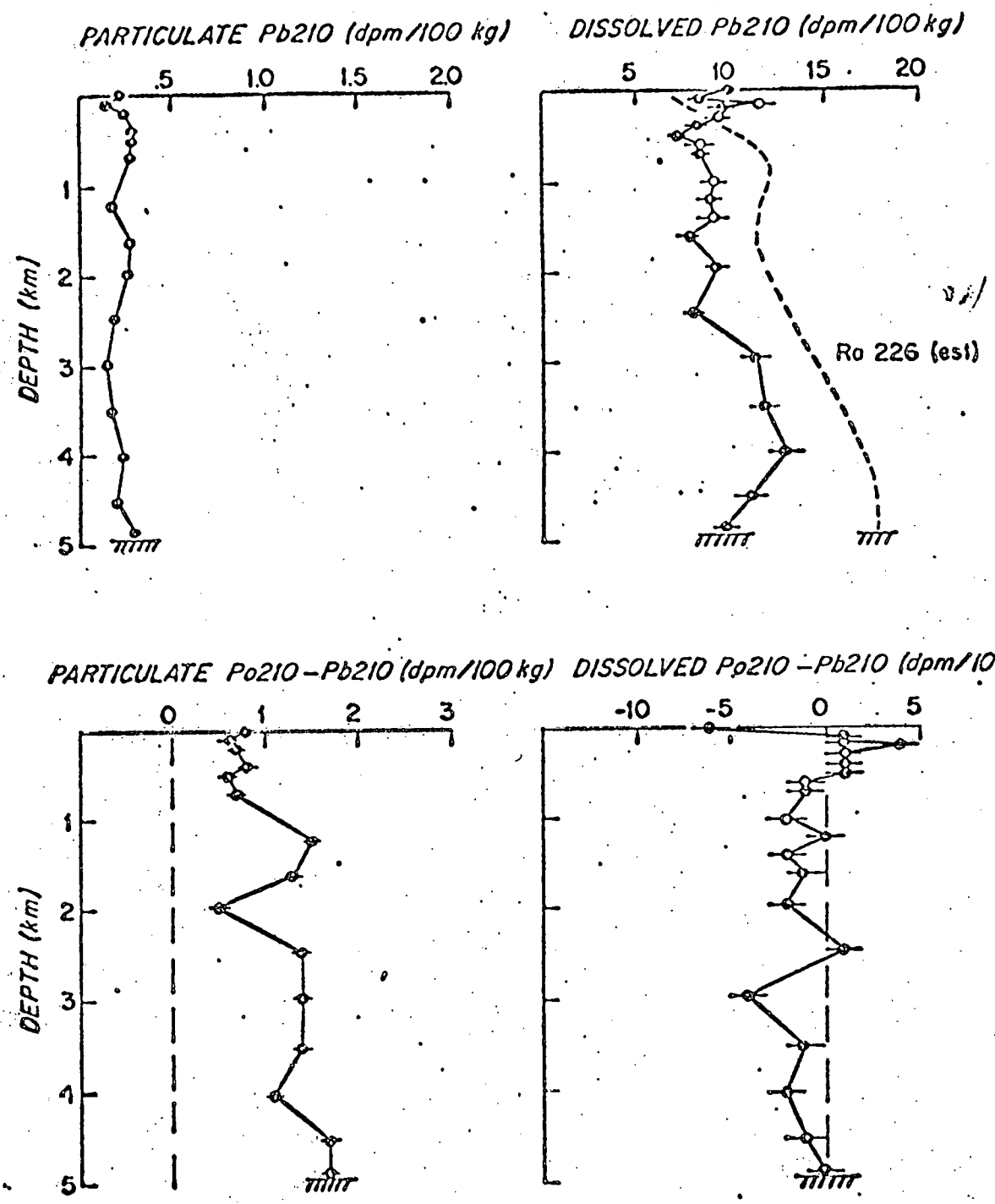
METEOR 32
STATION 21

Fig. 2e



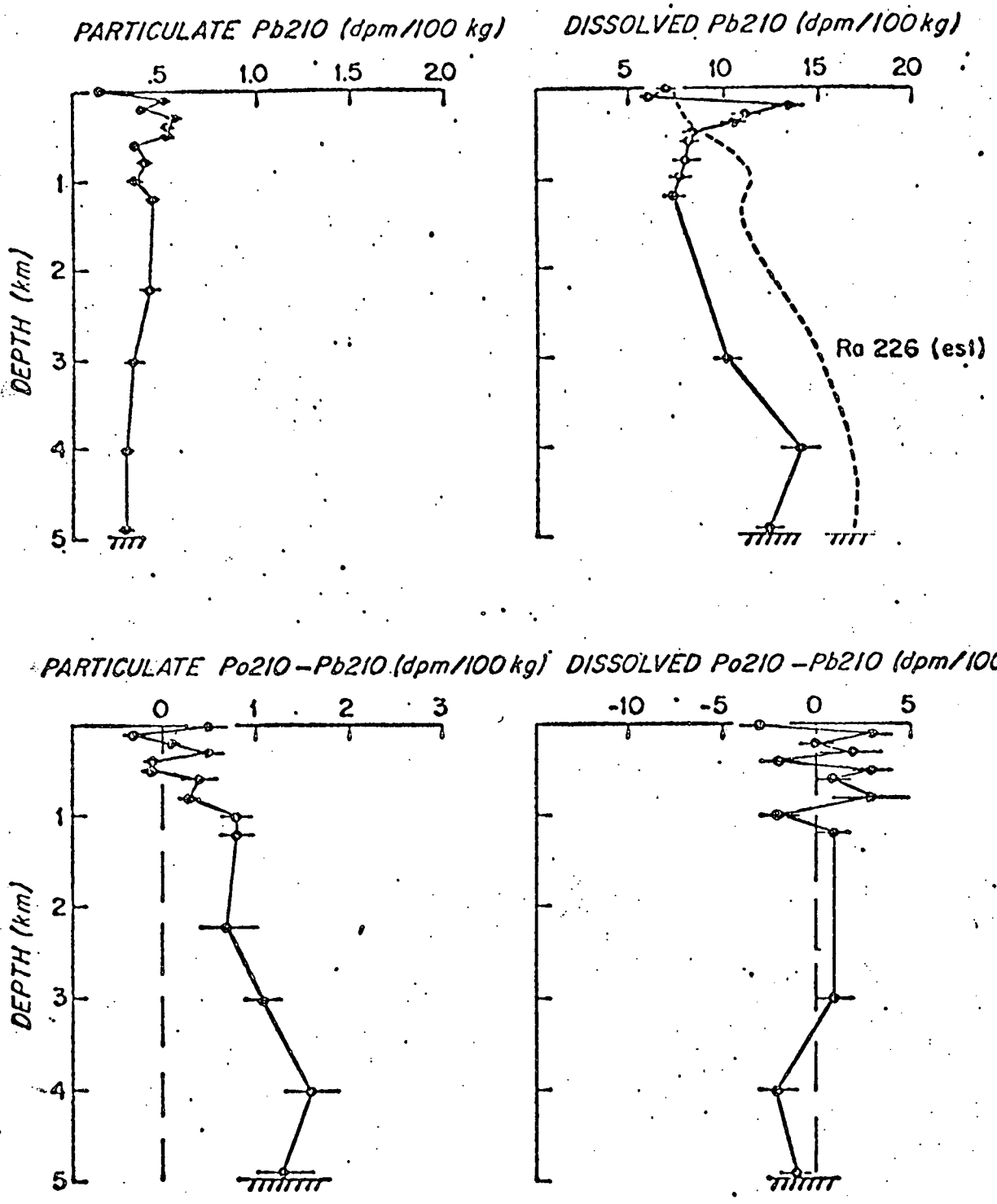
METEOR 32
STATION 22

Fig. 2



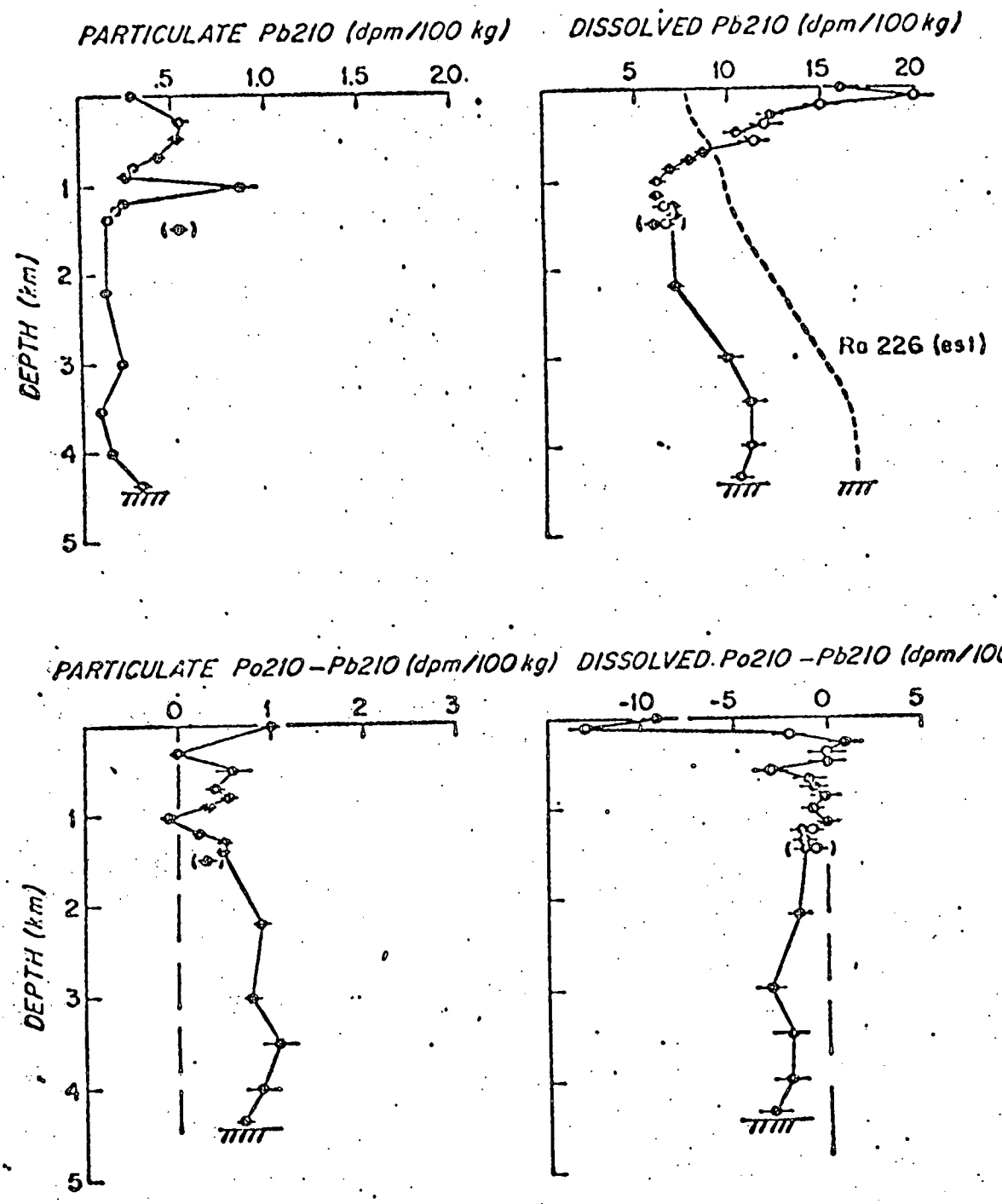
METEOR 32
STATION 23

Fig. 2g



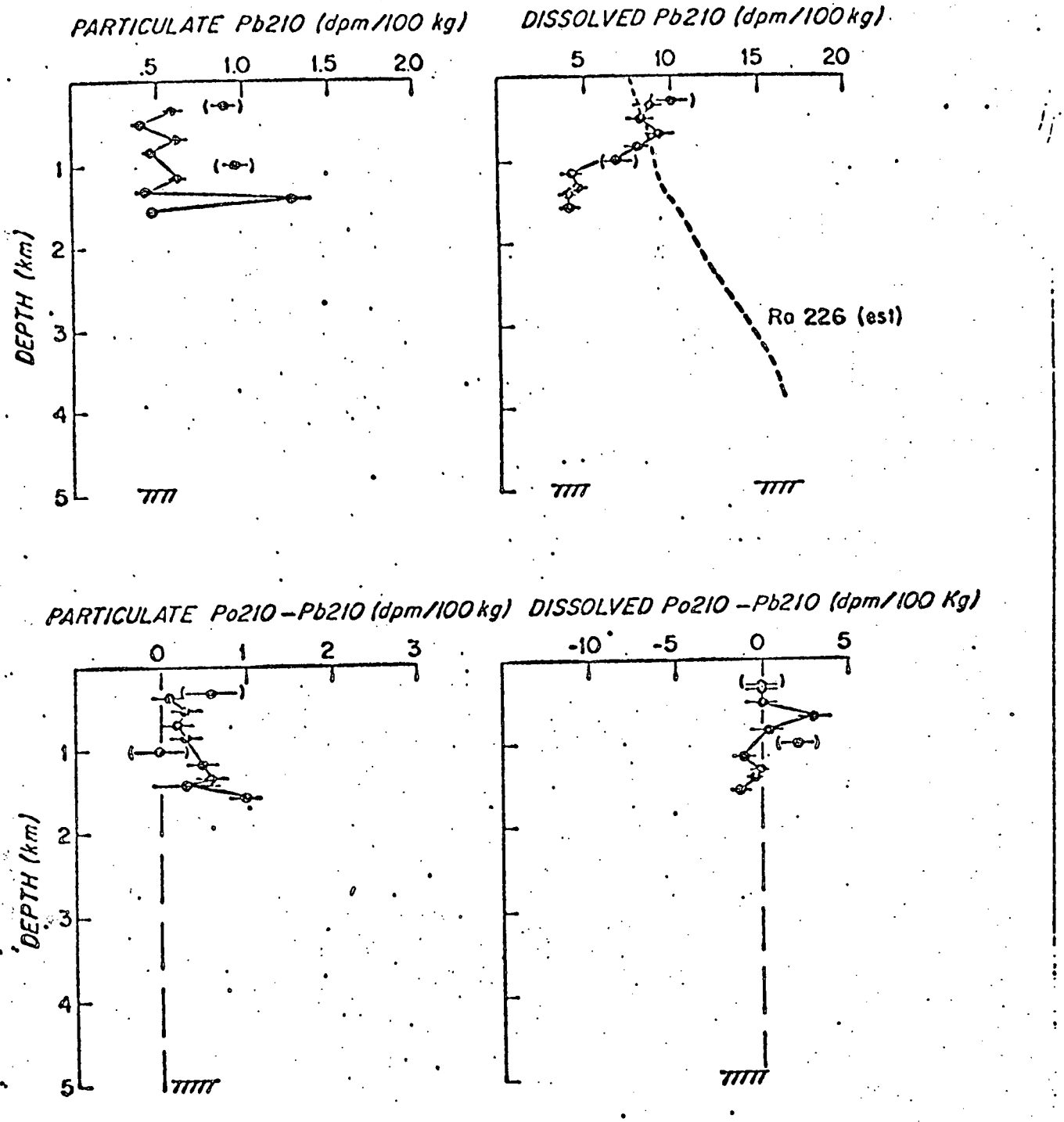
METEOR 32
STATION 27

Fig. 24



METEOR 32
STATION 32

Fig. 2i



METEOR 32
STATION 34

Fig. 2j

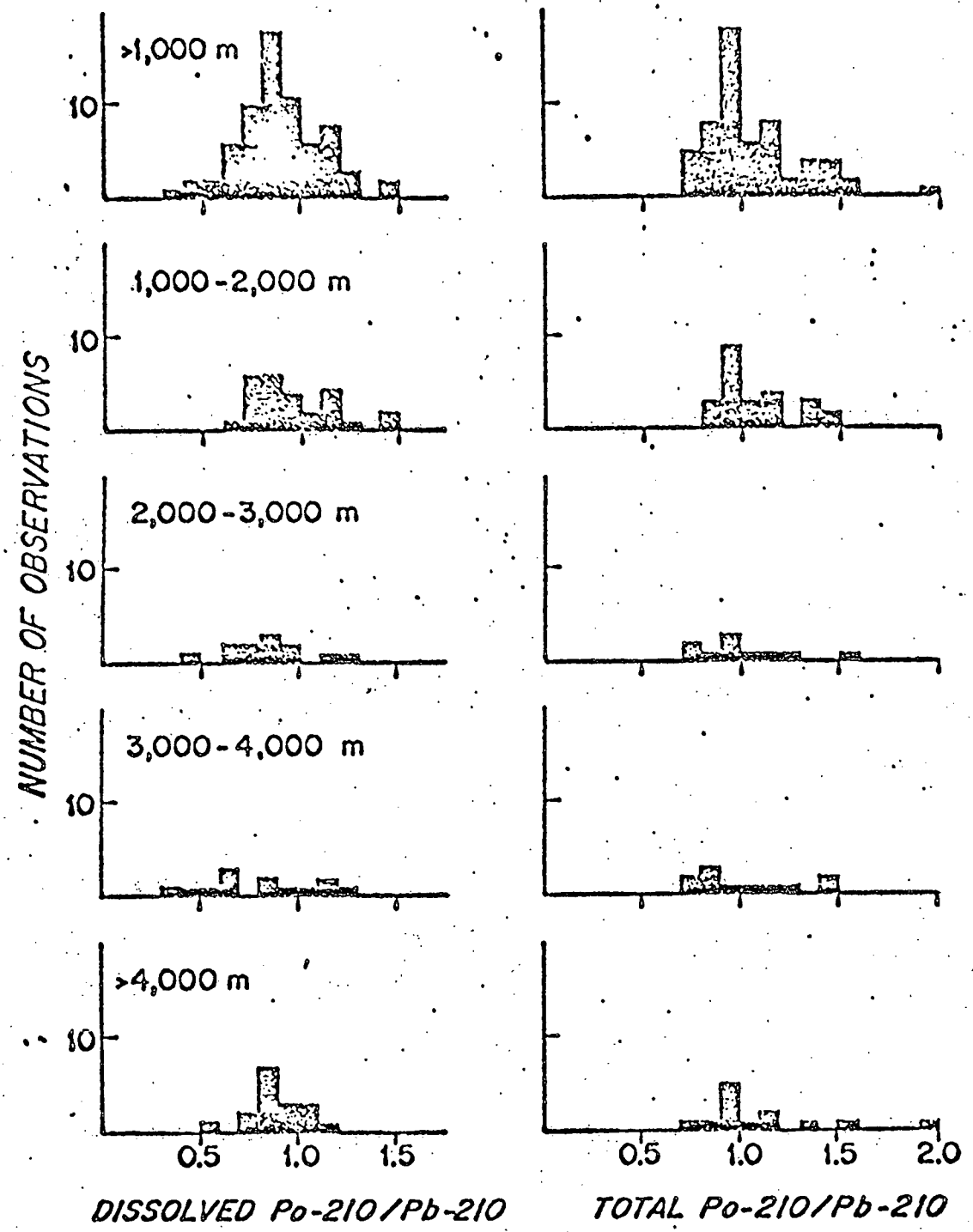

>1,000 m
1,000-2,000 m
2,000-3,000 m
3,000-4,000 m
>4,000 m
10
NUMBER OF OBSERVATIONS
0.5
1.0
1.5
2.0
DISSOLVED Po-210/Pb-210
TOTAL Po-210/Pb-210

Fig. 3

Appendix: Analytical results for F. S. "Meteor" cruise 32

Samples marked "NF" in the far right-hand column were not filtered; those marked by asterisk were from questionable sampler. Estimates of analytical precision are based on counting statistics and experience with replicate samples. Hydrographic data were furnished by W. Roether.

Meteor-32, Station 8, 21.5°N 66.5°W, 7-8 November 1973, 5440 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)
7	--	36.420	1.3	11.2	.31	--	11	1.6	--
95	--	36.626	.8	16	.22	--	14	1.1	--
295	17.508	36.451	1.6	12.7	.31	--	16	.6	--
613	12.008	35.548	8.6	8.5	.87	--	8	1.8	--
798	7.704	34.966	18.9	7.5	.43	--	7.2	.8	--
1497	4.110	35.003	12.4	3.1	.56	--	3	2.3	--
2592	2.776	34.961	23.9	4.6	.34	--	3.9	1.0	--

All samples were collected in 270-l stainless-steel Gerard barrels.
Mean estimated analytical precision (coefficient of variation)

a) Dissolved Pb-210, 7%
b) Particulate Pb-210, 10%
c) Dissolved Po-210, 19%
d) Particulate Po-210, 18%

Meteor-32, Station 12, 14.5°N 66.0°W, 11-12 November 1973, 4880 m.

Depth	Pot. Temp.	Sal.	Si	Pb-210			Po-210		
				Diss.	Part.	Tot.	Diss.	Part.	Tot.
(m)	(°C)	(°/₀₀)	(µm/kg)	(dpm/100 kg)					
8	28.042	34.213	3.0	13.8	1.7	--	3	1.6	--
48	28.001	34.271	2.9	12.8	2.1	--	5	1.0	--
118	25.129	36.613	1.2	17	.48	--	16	1.1	--
298	15.909	36.136	4.1	10.9	.77	--	14	1.0	--
593	7.763	34.856	19.3	7.5	.81	--	5	1.5	--
791	5.753	34.837	24.7	6.4	.51	--	6	.8	--
1188	4.337	34.963	26.2	5.0	.53	--	5.0	1.3	--
1486	4.050	34.972	27.1	4.1	.76	--	6	1.2	--
1784	3.959	34.977	27.6	4.5	.71	--	3.3	1.5	--
2183	3.885	34.977	27.9	4.9	.81	--	2.0	2.2	--
2489	3.858	34.983	27.9	4.4	.74	--	3	1.6	--
3187	3.858	34.985	27.9	4.7	.78	--	1.8	1.5	--
3983	3.846	34.976	28.0	4.4	.85	--	5	1.8	--
4779	3.853	34.982	28.2	3.8	.74	--	4	.5	--
4849	3.843	34.981	28.6	4.0	.68	--	4	2.1	--

All samples were collected in 270-l stainless-steel Gerard barrels.
Mean estimated analytical precision (coefficient of variation)

a) Dissolved Pb-210, 7%
b) Particulate Pb-210, 8%
c) Dissolved Po-210, 28%
d) Particulate Po-210, 19%

Meteor-32, Station 15, 14.7°N 57.5°W, 17-18 November 1973, 5370 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)	
7	27.250	34.774	3.2	21	.33	--	.2	1.6	--	
78	27.318	36.435	1.0	--	--	21	--	--	16	NF
149	23.429	36.989	.8	15	.46	--	17	1.2	--	
200	--	36.691	2.1	--	--	15	--	--	25	NF
401	12.386	35.582	8.2	9.5	.48	--	10	.9	--	
601	7.988	34.935	18.4	--	--	8.4	--	--	7.5	NF
799	6.254	34.787	23.8	7.8	.34	--	6.0	1.0	--	
1191	5.087	34.970	18.9	--	--	7.5	--	--	6.5	NF
1813	3.625	34.984	14.9	2.6	1.4	--	3.1	4.9	--	*
2615	2.784	34.956	22.3	4.0	.41	--	4.8	2.0	--	
3215	2.340	34.932	25.8	--	--	4.8	--	--	7.0	NF
3813	1.986	34.902	31.3	3.9	.24	--	4.6	1.2	--	
4409	1.824	34.893	36.0	--	--	4.3	--	--	3.6	NF
4806	1.673	34.879	46.8	3.7	.21	--	2.9	1.4	--	
5200	1.436	34.840	61.4	2.2	1.07	--	2.6	3.7	--	
5344	1.385	34.837	63.6	2.9	.51	--	2.6	2.6	--	

All samples were collected in 270-l stainless-steel Gerard barrels.
Mean estimated analytical precision (coefficient of variation)

a) Dissolved and total Pb-210, 8%
b) Particulate Pb-210, 10%
c) Dissolved and total Po-210, 14%
d) Particulate Po-210, 11%

Meteor-32, Station 18, 15.7°N 48.5°W, 21-22 November 1973, 3820 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/oo)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)
6	--	36.432	1.0	21	.54	--	5	1.4	--
59	25.806	36.900	.6	15.8	.61	--	7	1.9	--
84	23.857	37.154	.4	14.3	.85	--	11	2.6	--
112	22.694	37.201	.5	14.3	.28	--	17	.7	--
142	--	37.070	.8	12.0	1.08	--	16	1.3	--
211	17.671	36.472	2.9	11.8	.41	--	13	.6	--
295	16.671	35.867	6.3	11.3	.42	--	11	.7	--
392	11.680	35.405	10.9	9.1	.32	--	9.5	.8	--
619	8.277	34.972	17.8	7.2	.96	--	6.6	2.0	--
713	6.787	34.827	22.3	7.9	.36	--	7.0	.8	--
804	6.188	34.775	24.3	8.1	.37	--	6.5	1.0	--
980	5.435	34.840	24.4	7.9	.46	--	6.7	1.5	--
1144	5.045	34.958	22.1	7.5	.27	--	9.6	.6	--
1369	4.341	34.994	19.1	7.2	.37	--	8.1	.8	--
1970	3.426	34.982	20.8	8.1	.42	--	6.8	.9	--
2464	2.805	34.964	28.8	7.0	.67	--	6.8	2.1	--
2717	2.570	34.946	32.8	6.8	1.02	--	4.9	2.9	--
3208	2.390	34.931	37.5	7.8	1.6	--	4.9	3.1	--

Station 18 (cont.)

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)
3504	2.232	34.919	40.5	7.2	.92	--	3.5	3.5	--
3788	2.136	34.918	42.4	6.6	.95	--	3.4	2.9	--

Samples at 1369 m and above were collected in 270-l stainless-steel Gerard barrels; samples at 1970 m and below were collected in pairs of 30-l PVC Niskin bottles.

Mean estimated analytical precision (coefficient of variation)

a) Dissolved Pb-210, 7%
b) Particulate Pb-210, 9%
c) Dissolved Po-210, 13%
d) Particulate Po-210, 15%

Meteor-32, Station 21, 16.3°N 41.1°W, 24-25 November 1973, 4690 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)	
7	25.909	36.977	.5	18	1.11	--	8	1.3	--	
47	26.011	37.259	.5	17	.55	--	7	1.9	--	
97	23.605	37.287	.5	17	.27	--	17	1.5	--	
147	21.063	37.112	.7	13.3	1.25	--	19	1.6	--	
194	18.640	36.702	1.5	--	--	15.5	--	--	19	NF
247	16.844	36.361	2.5	12.0	.26	--	13	1.1	--	
396	12.790	35.654	7.9	7.0	.33	--	10	1.0	--	
489	11.058	35.388	11.4	--	--	9.7	--	--	9	NF
595	8.857	35.099	16.6	6.4	1.03	--	5.6	2.1	--	
791	6.563	34.880	22.9	7.4	.28	--	6.5	.9	--	
980	5.725	34.914	23.3	8.4	.45	--	6.4	1.0	--	
1176	5.108	34.971	21.8	Lost	.46	--	Lost	1.2	--	
1468	4.280	35.003	19.4	7.6	.45	--	7.1	1.5	--	*
1966	3.306	34.972	21.7	7.5	.40	--	8.9	1.5	--	
2462	--	34.950	22.1	8.0	.36	--	7.2	.8	--	

All samples were collected in 270-l stainless-steel Gerard barrels.
Mean estimated analytical precision (coefficient of variation)

a) Dissolved and total Pb-210, 7%
b) Particulate Pb-210, 9%
c) Dissolved and total Po-210, 11%
d) Particulate Po-210, 14%

I :or-32, Station 22, 16.5°N 37.0°W, 26-27 November 1973, 5450 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/oo)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)
7	25.742	37.046	.4	17	--	--	2	--	--
77	24.060	37.288	.3	15	--	--	8	--	--
156	19.920	36.996	.8	16	--	--	15	--	--
236	14.588	35.910	6.0	9.5	--	--	12	--	--
295	13.130	35.661	8.2	10.2	--	--	10	--	--
345	11.986	35.486	9.9	10.6	--	--	9	--	--
394	11.132	35.360	11.6	8.4	--	--	11	--	--
492	9.567	35.164	15.4	8.6	--	--	9	--	--
684	7.290	34.909	21.4	9.3	--	--	9	--	--
881	6.104	34.856	24.4	10.0	--	--	6.2	--	--
1176	5.186	34.975	22.2	8.8	--	--	5.4	--	--
1569	4.053	34.996	20.6	7.3	--	--	8	--	--
1963	3.376	34.976	22.2	9.0	--	--	8	--	--
2356	2.932	34.954	27.8	8.2	--	--	6.6	--	--
2749	2.631	34.942	32.7	9.5	--	--	7	--	--
3282	2.339	34.924	38.2	11.7	--	--	7	--	--
3777	2.130	34.904	42.1	11.1	--	--	9	--	--
4272	2.007	34.895	45.1	10.7	--	--	10	--	--

Station 22 (cont.)

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss.	Pb-210 Part.	Pb-210 Tot.	Po-210 Diss.	Po-210 Part.	Po-210 Tot.
				(dpm/100 kg)					
4768	1.877	34.883	48.6	9.4	--	--	8.4	--	--
5215	1.834	34.882	49.2	8.9	--	--	8.1	--	--
5414	1.835	34.889	--	8.7	--	--	7.4	--	--

All samples were collected in 30-l PVC Niskin bottles.
Mean estimated analytical precision (coefficient of variation)
a) Dissolved Pb-210, 7%
b) Dissolved Po-210, 15%

Me r-32, Station 23, 16.5°N 31.9°W, 28 November 1973, 4940 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)	
7	25.352	36.713	.3	9.9	.22	--	4.3	1.0	--	
96	21.299	36.903	2.6	8.3	.15	--	9.7	.8	--	
145	17.845	36.517	4.2	--	--	11.9	--	--	14	NF
195	15.921	36.178	8.5	9.6	.24	--	14	.9	--	
294	12.713	35.616	8.5	--	--	9.7	--	--	11	NF
392	10.968	35.358	12.0	8.3	.29	--	9.4	1.1	--	
510	8.889	35.071	16.6	7.2	.28	--	8.4	.9	--	
610	7.740	34.949	19.8	--	--	8.8	--	--	8.2	NF
710	7.454	34.915	20.6	8.5	.28	--	7.9	1.0	--	
1008	5.633	34.913	24.3	--	--	9.4	--	--	8.7	NF
1206	5.202	34.989	22.0	9.0	.18	--	8.5	1.7	--	
1403	4.556	35.006	21.0	--	--	9.3	--	--	8.7	NF
1600	3.991	35.001	21.7	7.8	.28	--	7.2	1.6	--	
1964	3.432	34.978	22.8	9.4	.27	--	7.5	.8	--	
2456	2.906	34.956	28.0	8.1	.19	--	9.1	1.6	--	
2948	2.557	34.938	34.2	11.4	.15	--	7.1	1.6	--	
3515	2.271	34.918	40.4	11.8	.18	--	11	1.6	--	
4014	2.032	34.898	46.4	13	.24	--	11	1.3	--	

Station 23 (cont.)

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)
4513	1.947	34.896	49.1	11.2	.20	--	10	1.9	--
4873	1.870	34.878	49.7	9.8	.31	--	10	2.0	--

Samples at 1600 m and above were collected in 270-l stainless-steel Gerard barrels; samples at 1964 m and below were collected in pairs of 30-l PVC Niskin bottles.
Mean estimated analytical precision (coefficient of variation)

a) Dissolved and total Pb-210, 7%
b) Particulate Pb-210, 10%
c) Dissolved and total Po-210, 10%
d) Particulate Po-210, 12%

M or-32, Station 27, 21.7°N 24.0°W, 2 December 1973, 4950 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)
8	23.208	36.630	.1	7.0	.16	--	4	.7	--
96	19.344	36.420	2.3	6.6	.51	--	10	.2	--
195	16.978	36.473	1.9	13.4	.38	--	13	.5	--
294	14.837	36.046	4.1	11.2	.56	--	13	1.1	--
393	13.304	35.797	5.6	10.6	.52	--	9	.4	--
492	11.812	35.572	8.2	8.3	.52	--	11	.4	--
591	10.271	35.386	11.9	8.2	.35	--	9	.7	--
789	7.771	35.096	18.4	8.0	.40	--	11	.7	--
985	6.310	35.004	21.1	7.7	.35	--	6	1.1	--
1181	5.773	35.066	19.9	7.3	.44	--	8	1.2	--
2216	3.276	35.004	28.2	Lost	.42	--	Lost	1.1	--
3014	2.422	34.934	37.0	10.2	.33	--	11	1.4	--
4002	2.025	34.898	44.8	14.1	.31	--	12	1.9	--
4894	1.978	34.898	46.6	12.4	.30	--	11	1.6	--

Samples at 1181 m and above were collected in 270-l stainless-steel Gerard barrels; samples at 3014 m and below were collected in pairs of 30-l PVC Niskin bottles.

Mean estimated analytical precision (coefficient of variation)

a) Dissolved Pb-210, 7%
b) Particulate Pb-210, 9%
c) Dissolved Po-210, 14%
d) Particulate Po-210, 26%

Meteor-32, Station 32, 33.8°N 13.4°W, 11 December 1973, 4440 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss. (dpm/100 kg)	Pb-210 Part. (dpm/100 kg)	Pb-210 Tot. (dpm/100 kg)	Po-210 Diss. (dpm/100 kg)	Po-210 Part. (dpm/100 kg)	Po-210 Tot. (dpm/100 kg)	
7	19.005	36.628		16	.29	--	7.2	1.3	--	
97	18.954	36.619		--	--	20	--	--	7.8	NF
196	14.823	36.041		--	--	15	--	--	14	NF
295	13.874	35.935		12.3	.55	--	11.6	.60	--	
393	12.918	35.800		--	--	12.6	--	--	12.7	NF
491	12.186	35.677		10.4	.53	--	10.6	1.1	--	
590	11.317	35.579		--	--	11.9	--	--	9.7	NF
687	10.758	35.556		8.8	.43	--	7.9	.82	--	
787	10.403	35.654		7.9	.30	--	7.2	.85	--	
886	9.887	35.677		6.9	.25	--	6.8	.58	--	
1034	9.445	35.768		6.2	.86	--	5.4	.8	--	
1182	--	35.829		6.2	.24	--	6.2	.46	--	
1280	8.821	35.818		7.0	.20	--	5.7	.70	--	
"	"	"		--	--	6.7	--	--	6.4	NF
1379	8.183	35.751		7.0	.16	--	5.8	.64	--	
1477	7.426	35.636		5.9	.54	--	4.7	.8	--	*
"	"	"		--	--	6.8	--	--	6.7	NF*
2195	3.701	35.072		7.6	.14	--	6.1	1.0	--	

Si on 32 (cont.)

Depth (m)	Pot. Temp. (°C)	Sal. (°/oo)	Si (µm/kg)	Pb-210 Diss.	Pb-210 Part.	Pb-210 Tot.	Po-210 Diss.	Po-210 Part.	Po-210 Tot.
				(dpm/100 kg)					
3021	2.522	34.940		10.0	.23	--	6.9	1.0	--
3519	2.236	34.910		11.2	.21	--	9.2	1.3	--
4018	2.112	34.900		11.2	.16	--	9.1	1.1	--
4368	2.071	34.897		10.6	.32	--	7.5	1.0	--

Samples at 1477 m and above were collected in 270-l stainless-steel Gerard barrels; samples at 2195 m and below were collected in pairs of 30-l PVC Niskin bottles.

Mean estimated analytical precision (coefficient of variation)

a) Dissolved and total Pb-210, 7%
b) Particulate Pb-210, 11%
c) Dissolved and total Po-210, 8%
d) Particulate Po-210, 13%

Meteor-32, Station 34, 38.5°N 11.5°W, 13 December 1973, 4930 m.

Depth (m)	Pot. Temp. (°C)	Sal. (°/₀₀)	Si (µm/kg)	Pb-210 Diss.	Pb-210 Part.	Pb-210 Tot.	Po-210 Diss.	Po-210 Part.	Po-210 Tot.
				(dpm/100 kg)					
288	12.529	35.767		10.2	.89	--	10	1.5	--
359	11.989	35.699		9.2	.59	--	8.7	.7	--
521	11.300	35.646		8.0	.39	--	8.2	.7	--
682	12.004	36.075		6.7	.62	--	9.3	.8	--
842	11.473	36.111		7.7	.46	--	8.0	.8	--
1004	11.400	36.252		4.7	.96	--	6.8	1.0	--
1165	10.902	36.247		5.3	.62	--	4.2	1.1	--
1326	9.954	36.115		4.7	.43	--	4.6	1.0	--
1407	8.978	35.933		4.3	1.3	--	3.9	1.6	--
1569	6.952	35.555		5.3	.48	--	4.1	1.5	--

All samples were collected in 270-l stainless-steel Gerard barrels.
Mean estimated analytical precision (coefficient of variation)

a) Dissolved Pb-210, 8%
b) Particulate Pb-210, 10%
c) Dissolved Po-210, 11%
d) Particulate Po-210, 22%

FLADEN GROUND EXPERIMENT 1976

1) Proposed R/V KNORR cruise track and station work

2) Cruise plans for R/V METEOR

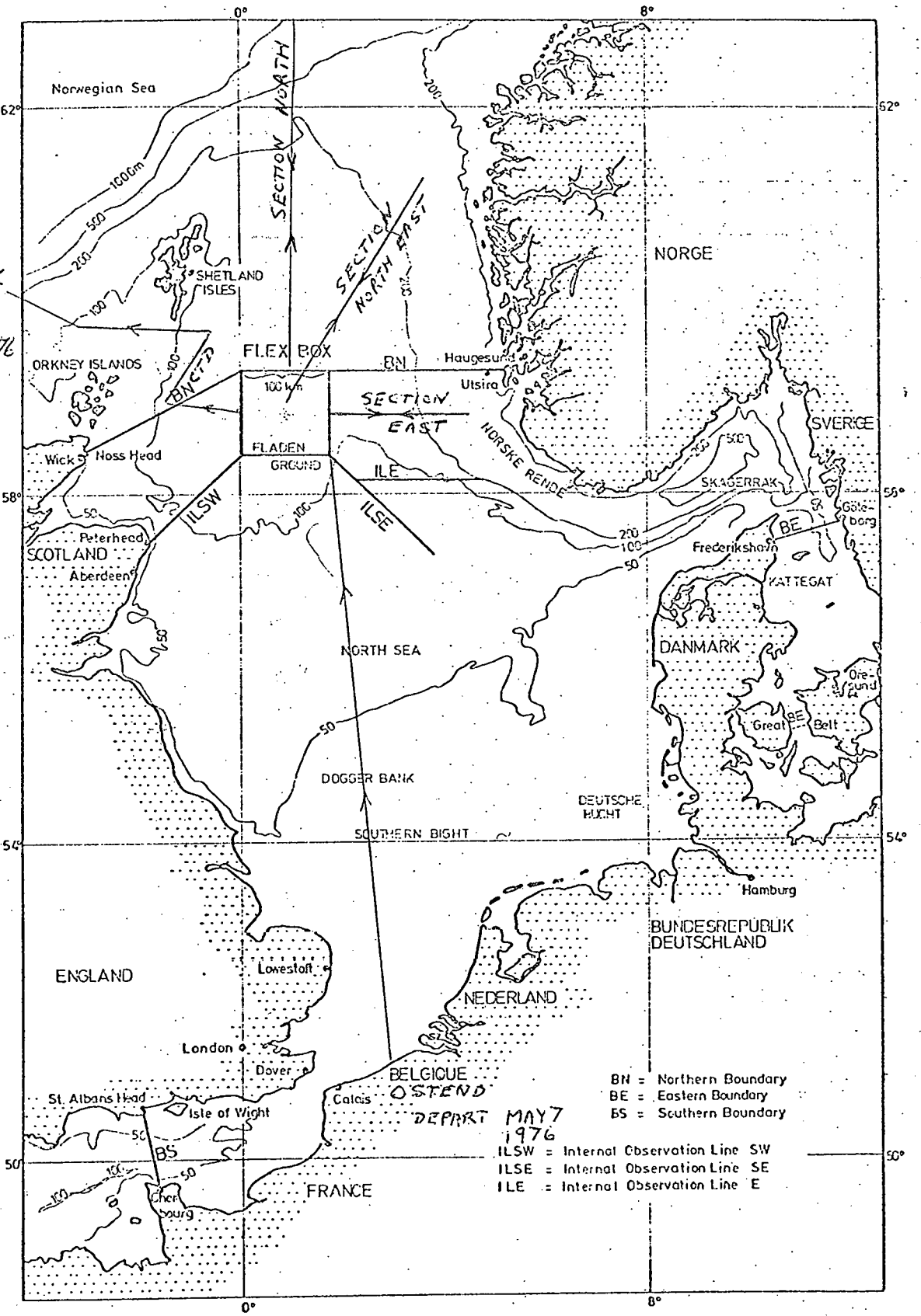
3) FLEX information update 4

4) FLEX information update 5

5) Report on the FLEX plankton studies workshop

PROPOSED CRUISE TRACK R/V "KNORR" MAY 7 - JUNE 6 1976

Fig. 1 Observation Lines and Areas in JONSDAP '76



TENTATIVE CRUISE SCHEDULE R/V KNORR CRUISE 54

MAY 5 - JUNE 4, 1976

OSTEND, BELGIUM TO REYKJAVIK, ICELAND

May 5	Depart Ostend
May 5 - May 7	Transect to FLEX Box; Coring
May 7 - May 11	FLEX Box I; CTD Sections, Large Volume Water Sampling, Hydrostations; Coring, Plankton Tows
May 11 - May 13	Section East; CTD, Hydrostations, Coring, Plankton Tows, Large Volume Water Sampling
May 13 - May 16	FLEX Box II; work as FLEX Box I
May 17 - May 20	Section North; work as Section East
May 20 - May 24	FLEX Box III; work as FLEX Box I
May 24 - May 26	Section Northeast; work as Section East
May 26 - May 30	FLEX Box IV; work as FLEX Box I
May 30 - June 4	Transect to Iceland; CTD's Hydrostations, Large Volume Sampling, Coring in Faroes-Scotland Overflow and North Atlantic
June 4	Arrive Reykjavik

CRUISE DATES WILL PROBABLY CHANGE BY TWO DAYS

MAY 7 TO JUNE 6

April 15
DWSpencer

HYDRO STATION WORK

1) Hydrocast CTD Rosette (10 bottles) Nutrients, oxygen, particulate
2) Hydrocast Wire (5 bottles) matter, tritium-He^3, salinity, temp.
3) Box Core (Johnson)
4) Core (Bowen)
5) Plankton Tows (Bowen)
6) Plankton Tows (Spencer)
7) Large Volume Casts (Bowen) Sr^{90}, Cs^{137}, Transuranics
8) Large Volume Casts (Spencer) Pb^{210}, Po^{210}
9) Radium - 228, 226 Casts
10) Insitu Filtration
11) Plankton Tows, etc. (German Scientists)
12) Other Work (German Scientists)

SCIENTIFIC PARTY

R/V KNORR CRUISE 54

1.	Spencer, Derek	WHOI
2.	Brewer, Peter	WHOI
3.	Kadar, Susan	WHOI
4.	Smith, Clarence	WHOI
5.	Fleer, Alan	WHOI
6.	Sachs, Peter	WHOI
7.	Little, Kate	Student
8.	Livingston, Hugh	WHOI
9.	Ball, Lary	WHOI
10.	Anderson, Robert	Student
11.	Dykstra, Suzanne	WHOI
12.	Schroeder, Brian	WHOI
13.	Gschwend, Phillip	Student
14.	Johnson, Thomas	U. Minn.
15.	Elkins, S.	U. Minn.
16.	Vadnais, Romeo	SIO
17.	Houvenaghel, Guy	U. Brussels
18.	German Scientist	U. Hamburg
19.	German Scientist	U. Hamburg
20.	German Scientist	U. Hamburg
21.		
22.		
23.		

Inhalt

Contents

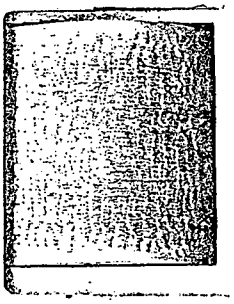
I. SCIENTIFIC PROGRAMME

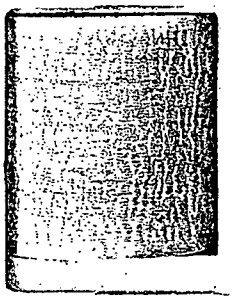
A. The FLEX programme and its relation to JONSDAP '76

Since several years investigations on marine ecosystems have been undertaken with increasing effort. One of the reasons may be that the manyfold interests in the utilization of the sea - of their resources, by ships, for recreation, but also for waste dumping - have lead to conflicts, advocates of unconditional utilization or even inconsiderate exploiting standing against defenders of rigorous protection measures. Arguing for a reasonable compromise taking as many interests into account as possible is difficult as long as there is no sufficient scientific background, consisting of precise quantitative information on the interactions between the various physical and chemical environmental influences on the one hand, and the biological processes on the other hand which include the complete food chain from the primary production of phytoplankton until men's interference by fishery.

Certainly there are already numerous investigations on partial aspects of ecosystems, but most of them are not satisfying the requests of models neither by the number of measured parameters nor by their precision or their temporal and spatial resolution. Models are necessary, however, for predicting the influences of any measures or natural events.

Among the scientists cooperating within the "Sonderforschungsbereich 94, Meeresforschung Hamburg" which by its interdisciplinary character offered good chances for systematic investigation on ecosystems, first plans for a joint research programme were developed and introduced to the North Sea oceanographic community during a meeting of the JONSIS group in 1973.
(= Joint North Sea Information System).





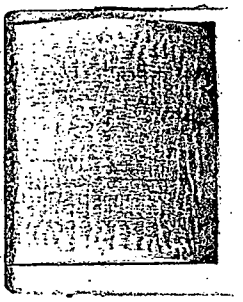
It proposed a three-month's experiment in spring 1976 in the Fladen Ground region of the northern North Sea, by cooperation of several research vessels.
The goal was defined: to investigate in a continuous and intensive manner the processes within the ecosystem during the phase of first spring heating and of the beginning of the spring plankton bloom.

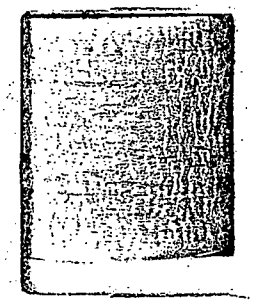
The Fladen Ground was selected because this region offers various favourable conditions for an undisturbed ecosystem. It is more or less free of direct coastal influences and it has sufficient water depths. There is regularly a thermocline developing during spring and summer, and net water transports are relatively small.

Another reason for proposing that location and that time was that the JONSIS group had decided one year before to carry out another large-scale experiment which was scheduled to measure the currents and water levels at the northern boundary of the North Sea. The goal of this experiment was to obtain sufficient data from simultaneous measurements for calculating the budget of inflow / outflow, for improving the North Sea tide models and the knowledge of the residual current system.

It was natural to link both projects also in time, and thus the planning was continued under the joint name "JONSDAP '76" (= Joint North Sea Data Acquisition Programme), meaning now "FLEX '76", for Fladen Ground Experiment, and "IN-OUT", for the current measurement programme. The latter project was lateron enlarged to the whole North Sea by French, Danish and Swedish participation, and complemented by several current meter profiles or stations within the interior of the North Sea.

During the Constitutional Meeting of ICES 1974 in Copenhagen the North Sea Working Group of the Hydrographc Committee recommended to support the work of the JONSIS Sub Group,





and thus a joint ICES / JONSIS Working Group was named and approved in order to finalize the planning. Several meetings followed until the end of 1975 during which the individual plans could be matched and an optimized programme could be agreed upon.

It became obvious, however, that neither the number of vessels available (indeed more than a dozen) nor the number of berths and facilities were sufficient to comply with all requests for participation, but on the other hand, also that there were some bottlenecks with some disciplines considering a several months activity at sea. Therefore not all parameters would at all times be measured to the desirable extent.

Nevertheless, all participants hope that the results of this experiment, a first in this kind and size, will at least bring a considerable step forward on the way to the understanding of ecosystems, being aware of course that one cannot expect a complete solution of all questions from such a first attempt.

B. R.V. "METEOR"'s tasks within FLEX '76

1. General Strategy

An area of about 100 km x 100 km side length was defined as working region, called "FLEX BOX", with its centre at about 58°50' N and 0°45' E. All participating vessels will be working within this area during the agreed period from mid of March until mid of June, 1976, with probably 5 to 6 German, 3 British, 2 Belgian, 1 Dutch, 1 Swedish an 1 US-American research vessels, supported by one or two research aircrafts. The majority of the vessels will work "roving", i.e. by running systematically profiles covering the whole area. "METEOR", however, (during her absence "ANTON DOHRN", too), and a Belgian vessel will work in a "stationary" manner, i.e. she will try to measure the temporal variations at a defined location, or within a defined water body as long as it can be marked.

These ships' measurements are to complement the records of numerous recording instruments (current meters, thermistor chains) moored in an array within the FLEX Box during the whole period of the experiment (see map, Fig. 1).

Part of these instruments will be moored by "METEOR" already during the preciding cruise No.40 C (4. - 16.3.) together with the "IN-OUT"-instruments. At the beginning of leg 2 of this cruise No. 41 the "IN-OUT"-instruments will be recovered by "METEOR", and some of them re-deployed additionally in the FLEX Box. The final recovery af all instruments will be undertaken during the end phase of leg 3 (June).

Summarizing: RV "METEOR"'s tasks are not only the central part of the German contribution to FLEX, but they may be considered, too, as being one of the most important parts of the whole FLEX programme, covering nearly its full period. It was therefore agreed that RV "METEOR" will act as a central communication station, being available for the exchange of informations and news as well as of important data between the participating vessels. A similar function will be practised ashore by the Fishery Laboratory in Aberdeen, Scotland.

2. Programmes of the various disciplines

During all three legs of this "METEOR" cruise (except the phases of deploy and recovery of moorings) a standard station programme will be carried out on a routine schedule with a 6-hourly repitition rate (0, 6, 12, 18 hours local time). For some special programmes there is a more (or less) frequent rate of measurements possible.
In the following paragraphs the various programmes are explained separately.

a) Physical Oceanography

Temperature, salinity and, thereby, density layering will be measured by means of the "Bathysonde" (CTD). One instrument of this type will be combined with a rosette sampler and be used during the standard stations in order to synchronize the chemical-biological sampling with the physical measurements. Between the standard stations another Bathysonde and a profiler will be used, the latter to obtain vertical profiles of the current shear. Data on sea waves will be transmitted from 4 "wave-rider" buoys deployed in the FLEX area and recorded several times per day on board of "METEOR". (DHI)

The optical measurements consist of vertical profiles of daylight intensity (by a quantameter) as well as of attenuation and scattering. Light absorption will be measured in various wave lengths. These measurements will be made at least during the standard stations. (IPO)

b) Chemistry

For investigating the inter-relations of the various bio-chemical parameters with each other it must be ensured that all samples for the individual measurements have been taken from the same major sample. That is why these samples will normally all be taken from one big bottle of the rosette sampler and subdivided for the various chemical and biological determinations. The following chemical components will be analyzed :

nitrate and nitrite, ammonium, phosphate and silicate (by means of an autoanalyzer);

the elements N, C and P from the particulate and the dissolved fractions (by means of a CHN-Analyzer and an autoanalyzer);

dissolved carbohydrates and amino acids (by column chromatography);

particulate total carbohydrate and proteins (by colorimetry).
(IOB)

c) Biology

The distribuiton of species and quantities of phytoplankton will be determined by counting from samples taken from the same bottles as the hydrographic samples.

Clorophyll will be measured by filtrating samples from the same source, and production rates by using the ^{14}C-method. The ^{14}C-measurements will be made "in situ" (from a drifting buoy) as well as on deck by a simulation method.
(BAH)

The chlorophyll determination from samples will be complemented by vertical profiles using a fluorometer which is combined with a light scattering recorder. (IHF)

Zooplankton investigations are limited to determinations of filtrated samples from the standard waterbottles (IHF) and to experimental determination of food uptake and excretion rates by means of counting and marking techniques. (UB, MLA)

The main microbiological work is the determination of bacteria which are forming colonies in cultures.
The samples will be taken by means of special sterile sampling techniques from 8 depths at the usual standard times.

Selected organisms will be isolated for physiological investgations to be made lateron.

Some investigations on bacterial parasites of bacteria will be made in addition, using newly developed techniques for isolation and determination of quantities. (IAB)

Moreover, the respiratory activity and the uptake of marked substances by aeorobic planktonic bacteria will be determined from samples taken 3 times per day from 3 selected depths. (UB)

d) Meteorology

Some of the meteorological parameters have an immediate influence on the investigated ecosystem. This concerns the physical oceanography (wind waves, winddrift currents, sea surface temperatures), as well as the biochemical processes (photosynthesis) with the primary production.

Therefore the 3-hourly usual routine weather observations will be increased (particularly by hourly wind and air temperature measurements) (SWA, M I) and in addition, solar and global radiation will be registrated using solarimeters and pyranometers. (IGM)

II. TEILNEHMENDE INSTITUTE

PARTICIPATING INSTITUTES

1. DHI — Deutsches Hydrographisches Institut
   Bernhard-Nochtstraße 78, D-2000 Hamburg 4

2. MI — Meteorologisches Institut der Universität Hamburg
   Bundesstraße 55, D-2000 Hamburg 13

3. IHF — Institut für Hydrobiologie und Fischereiwissenschaft der Universität Hamburg
   Palmaille 55, D-2000 Hamburg 50

4. IOB — Institut für Organische Chemie und Biochemie der Universität Hamburg
   Papendamm 6, D-2000 Hamburg 13

5. IAB — Institut für Allgemeine Botanik und Botanischer Garten der Universität Hamburg
   Jungiusstraße 6 - 8, D-2000 Hamburg 36

6. SFB — Sonderforschungsbereich 94, Meeresforschung, Universität Hamburg
   Bundesstraße 55, D-2000 Hamburg 13

7. BAH — Biologische Anstalt Helgoland
   D-2191 Helgoland

8. IGM — Institut für Geophysik und Meteorologie der Universität Köln D-5000 Köln 41
   Kerpener Straße 13

9. IFO — Institute of Physical Oceanography, University of Copenhagen
   Haraldsgade 6 DK-2200 Copenhagen N

10. UB — Laboratorium voor Ekologie en Systematiek, Vrije Universiteit Brussel
    A. Buyllaan 105 B-1050 Brüssel

11. MLA — Marine Laboratory, Dept. of Agriculture and Fisheries for Scotland
    P.O.Box 101 GB - Aberdeen AB9 8DB

III. Zeitplan

Time Table

Fahrtabschnitt Leg	1 :	Ab Hamburg	22. 3. 1976
		An Hamburg	15. 4. 1976
			24 Tage
Fahrtabschnitt Leg	2 :	Ab Hamburg	22. 4. 1976
		An Aberdeen	18. 5. 1976
			26 Tage
Fahrtabschnitt Leg	3 :	Ab Aberdeen	21. 5. 1976
		An Hamburg	16. 6. 1976
			26 Tage

Postanschrift ABERDEEN : / Postal address in ABERDEEN

Konsul der Bundesrepublik Deutschland
Mr. Andrew H.S. Lewis
23, Commercial Quay
GB - Aberdeen AB1 2NR

IV. 1 STAMMBESATZUNG "METEOR"

SHIP'S COMPLEMENT "METEOR"

Name	Funktion	Name	Funktion
Meyer, Uwe	Kapitän	Kuhn	Decksmann
Fietz	I. Offizier	Tebbens	1. Koch
Kettler	II. Offizier	Gotthardt	2. Koch
Hartwig	2.II.Offizier	Fischer	Koch
Santjer	III. Offzier	Tasser	Koch u. Bäcker
Kläuschen	1.Funk-Offizier	Mahnke	1. Steward
Mitschidin	2.Funk-Offizier	Hermann	Steward
Pakulat	Verm.Techniker u.3.Offizier	Wels	Steward
		Kalix	Steward
Rothstock	Ing.Nachrichten-technik	Nietupski	Steward
		Jüttner	Steward
Bettels	Ing.-Nachrichten-technik	Ammermann	Leit.Ingenieur
		Kuleisa	Masch. Ing.
Meyer, Christ.	HF-Techniker	Vorwerk	1. Maschinist
Tramp	Techn. Ang.	Mahrt	2. Maschinist
Ranalder	Bootsmann	Külper	3. Maschinist
Fink	Zimmermann	Gerbig	4. Maschinist
Kruse	Matrose	Kuschnereit	1. Elektriker
Neugebauer	Matrose	Paech	Elek.Assistent
Nagorsen	Matrose	Fellner	Storekeeper
Gschnitzer	Matrose	Gudehus	Ing.Assistent
Wilms	Matrose	Olbrich	Ing.Assistent
Borth	Matrose	Eilers	Ing.Assistent
Bagniewski	Matrose	Krebs	Ing.Assistent
Urban	Matrose	Holtappels	Motorenwärter
Zöger	Matrose	Hennecke	Motorenwärter
Jenß	Matrose	Gaden	Motorenwärter
Geil	Matrose	Wong	Wäscher

Bordwetterwarte

Abschnitt I

Franke, ORR Dipl.Meteorologe — Ochsenhirt — Funkwettertechn.

Abschnitt II und III

Dr. Puls, ORR Meteorologe — Bassek — Funkwettertechn.

Hospital

Dr.Gerloff Bordarzt (Abschnitt I)

Dr. NN Bordarzt (Abschnitt II und III)

IV. 2 Teilnehmende Wissenschaftler und Techniker

Participating Scientists and Technicians

N a m e	Fachgebiet	Institut
Backhaus, J., Dipl.-Oz.	Physikalische Ozeanographie	D H I
Becker, G. Dipl.-Oz.	Physikalische Ozeanographie	D H I
Behmann, W., cand.rer.nat.	Meteorologie	I G M
Biermann, Frau M.	Chemie	I O B
Buch, E., cand.rer.nat.	Meeresoptik	I P O
Carlson, H., Dipl.-Phys.	Physikalische Ozeanographie	D H I
Chilian, R., cand.rer.nat.	Meteorologie	M I
Daro, Mme. M.H.	Mikrobiologie	U B
Dittmer, K., cand.rer.nat.	Meteorologie	M I
Eberlein,K., Dipl.-Biol.	Chemie	I O B
Fichtner, H.	Chemie	I O B
Gamble, Dr. J.C.	Biologie	M L A
Hagmeier, Dr. E.	Biologie	B A H
Hammer, K.D., Dipl.-Biol.	Chemie	I O B
Hempel, R.	Physikalische Ozeanographie	D H I
Hentzschel,G. Dipl.-Biol.	Mikrobiologie	I A B
Heuer, Frau	Biologie	I H F
Höjerslev, Dr. N.K.	Meeresoptik	I P O
Huber, Dr. K.	Physikalische Ozeanographie	D H I
Hübner, H.	Physikalische Ozeanographie	D H I
Hühnerfuß, Dr. H.	Chemie	I O B
Joiris, Dr. C.	Biologie	U B
Kanje, Frau	Biologie	B A H
Kattner, G. Dipl.-Biol.	Chemie	I O B

N a m e	Fachgebiet	Institut
Kempe, P.	Physikalische Ozeanographie	D H I
König, Frl.	Chemie	I O B
Koltermann, K.P.,Dipl.-Oz.	Physikalische Ozeanographie	D H I
Krause, Dipl.-Biol.	Biologie	I H F
Küsters, Frau	Mikrobiologie	I A B
Lenz, W. Dipl.-Oz.	Physikalische Ozeanographie	S F B
Mittelstaedt, Dr. E.	Physikalische Ozeanographie	D H I
Neu, F.	Physikalische Ozeanographie	D H I
Öttig, Frl.	Chemie	I O B
Prahm, Frau Dr. G.	Physikalische Ozeanographie	D H I
Reuter, U., Dipl.-Met.	Meteorologie	I G M
Rubach, H.J.	Physikalische Ozeanographie	D H I
Rudloff, R., Dipl.-Geoph.	Physikalische Ozeanographie	S F B
Sanches	Biologie	I H F
Schaab, Frau B.	Chemie	I O B
Schmetz, J., cand.rer.nat.	Meteorologie	I G M
Stelter, G., Ing.(grad.)	Physikalische Ozeanographie	D H I
Tadday	Biologie	B A H
Trahms, Dr. K.J.	Biologie	I H F
Treutner	Biologie	B A H
Vollmer	Chemie	I O B
Weigel	Biologie	B A H
Westphal, J.,cand.rer.nat.	Meteorologie	M I
Wierhake, Frau H.	Biologie	I O B
Wöckel, P., Ing.(grad.)	Physikalische Ozeanographie	D H I
Wünschmann, W.	Physikalische Ozeanographie	D H I
Ziemkendorf, Frau	Biologie	I H F

1. Fahrtabschnitt
1st Leg

Fahrtleiter
chief scientist

Physik. Ozeanogr
physic. oceanogr

Meereschemie
marine chemistry

Biologie
biology

Meteorologie
meteorology

Einschiffung auf
embarkation

Ausschiffung auf
disembarkation

V. Personalplan

1. Fahrtabschnitt : Hamburg - Hamburg (22. 3. - 15. 4. 1976)
1st Leg

		Institut / Institute	Anzahl / Number
Fahrtleiter chief scientist	: Mittelstaedt	DHI	1
Physik. Ozeanographie: physic. oceanography	Backhaus, Becker, Kempe, Rubach, Stelter, Wünschmann	DHI	6
	Buch	IPO	1
Meereschemie marine chemistry	: Hammer, Kattner, König, Wierhake	IOB	4
Biologie biology	: Hagmeier, Tadday, Treutner	BAH	3
	Trahms, Krause, Heuer	IHF	3
	Hentzschel, Küsters	IAB	2
	Joiris, Daro	UB	2
Meteorologie meteorology	: Reuter	IGM	1
	Westphal	MI	1
			24

Einschiffung auf See (von "Anton Dohrn") : Weichart
embarkation

Ausschiffung auf See (auf "Anton Dohrn") : Joiris
disembarkation

2. Fahrtabschnitt : Hamburg - Aberdeen (22. 4. - 18. 5. 1976)
2nd Leg

		Institut / Institute	Anzahl / Number
Fahrtleiter / chief scientist	: Koltermann	DHI	1
Physik. Ozeanographie / physic. oceanography	: Huber, Hempel, Hübner,	DHI	5
	Carlson, Wöckel	DHI	
	Lenz	SFB	1
	Höjerslev	IPO	1
Meereschemie / marine chemistry	: Eberlein, Fichtner, Vollmer, Schaab	IOB	4
Biologie / biology	: Kanje, Öttig, Treutner	BAH	3
	Trahms, Sanches, Ziemkendorf	IHF	3
	Hentzschel, Küsters	IAB	2
	Gamble	MLA	1
	Joiris (Einschiffung auf See)	UB	1
Meteorologie / meteorology	: Behmann	IGM	1
	Dittmer	MI	1
			24

Aberdeen: Ausschiffung / disembarkation:
Koltermann, Carlson, Lenz, Hübner, Wöckel, Behmann, Dittmer, Treutner, Trahms, Eberlein, Fichtner, Vollmer, Schaab, Gamble.

Einschiffung / embarkation:
Prahm, Becker, Neu, Stelter, Rudloff, Schmelz, Chilian, Weigel, Krause, Hammer, Hühnerfuß, Wierhake, Biermann, Daro.

3. Fahrtabschnit
3rd Leg

Fahrtleiter
chief scientist

Physik. Ozeanogra
physic. oceanogra

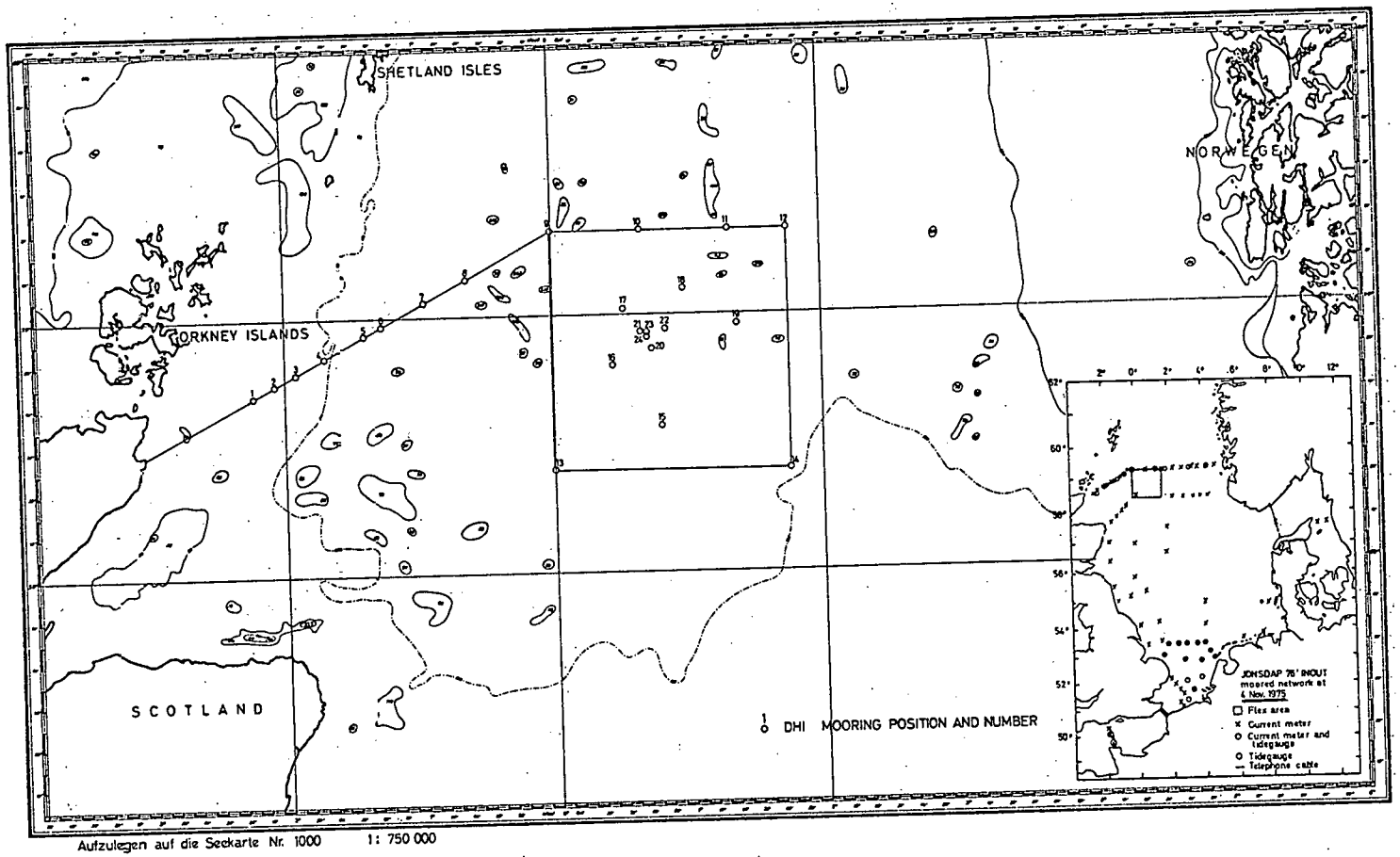
Meereschemie
marine chemistry

Biologie
biology

Meteorologie
meteorology

3. Fahrtabschnitt : Aberdeen - Hamburg (21. 5. - 16. 6. 1976)
3rd Leg

		Institut / Institute	Anzahl / Number
Fahrtleiter chief scientist	: Prahm	DHI	1
Physik. Ozeanographie: physic. oceanography	Becker, Huber, Hempel.	DHI	5
	Neu, Stelter		
	Rudloff	SFB	1
	Höjerslev	IPO	1
Meereschemie marine chemistry	: Hammer, Hühnerfuß	IOB	4
	Wierhake, Biermann		
Biologie biology	: Kanje, Öttig, Weigel	BAH	3
	Krause, Sanches, Ziemkendorf	IHF	3
	Hentzschel, Küsters	IAB	2
	Joiris, Daro	UB	2
Meteorologie meteorology	: Schmetz	IGM	1
	Chilian	MI	1
			24



Aufzulegen auf die Seekarte Nr. 1000 1: 750 000

FLEX Information 4

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Telephone: (040) 4123-4236

To:
- the JONSDAP 76 Co-ordinators
- the FLEX Chief Scientists [1]
  (names and addresses: see Annex 8)

Hamburg, 12 March, 1976

1. Ship schedules and Programmes

An up-dated list of participating research vessels (Annex 1) shows radio call signs, cruise schedules, chief scientists as well as transmitter and receiver frequencies of each ship. Please, note the modifications of the cruise schedules of R.V. FRIEDRICH HEINCKE, R.V. CHALLENGER, R.V. KNORR, R.V. EXPLORER, NIEUWPOORT and R.V. SVANIC.

GERMANY

METEOR:
The position of R.V. METEOR, when doing stationary work, is supposed to be: 58°55'N/00°32'E.

FRIEDRICH HEINCKE:

A proposal for the first cruise of R.V. FRIEDRICH HEINCKE has been submitted by Mr. G. Wegner (Annex 2).

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[1] It would be appreciated if those who have received this document could copy the relevant parts for their colleagues who are interested. A limited number of copies is also available in Hamburg.

SWEDEN

As Dr. K. Gundersen (University of Göteborg) writes in a letter of 26 February, two of his students and two of Dr. David Dyrssen's students will participate in a cruise on the Fisheries Research Board's R.V. ARGOS from March 22 - April 8. Dr. A. Svansson will be Chief Scientist on this cruise. The ship will make two double crossings from the Norwegian coast (Egersund) to Scotland (Aberdeen) as part of the JONSDAP 76/INOUT project and will follow a track along the 58°26'N latitude, thus touching on the southern boundary of the FLEX square. There will be several stations (see below) consisting of extensive samplings for plant nutrients and other chemistry. Dr. Gundersen's students will be doing experimental work on nitrification and denitrification and Dr. Dyrssen's people will study alkalinity, phosphorous, and lipids. These data can be made available for the FLEX project.

ARGOS sampling stations on the southern boundary of the FLEX box (Source: March updater of John Ramster):

AR 13	58°26' N	1°44'30" E
AR 14	"	1°20' E
AR 15	"	1°00' E
AR 22	"	0°40' E
AR 23	"	0°20' E
AR 24	"	0°00' E

UNITED KINGDOM

Detailed cruise programmes for RRS CHALLENGER and RRS JOHN MURRAY have been submitted by Dr. R.H. Bruce and Mr. R. Williams, Institute for Marine Environmental Research, Edinburgh (Annex 3).

UNITED STATES

A tentative cruise schedule for R.V. KNORR Cruise 54 (May 5 - June 4) has been proposed by Dr. D.W. Spencer, Woods Hole Oceanographic Institution (Annex 4).

2. Oil rigs

According to informations of BP, Hamburg, there are at present two drilling oil rigs inside the FLEX box:

	I	II
Operator	Pan Ocean	Trans Ocean (Sea Search)
Rig	Odindrill semi-sub	Penrod 71 semi-sub
Classification	Brae Appraisal	Wildcat
Water depth	104 m	132.6 m
Position	58°44'53" N 01°17'41" E	58°42'34"N 00°31'38"E

3. Naval exercise

There will be a naval exercise in the northern North Sea during the period 20-30 May. The critical periods in relation to the FLEX box are 20 - 22 May and, especially, 26 - 27 May.

4. Intercomparison

An intercalibration schedule is proposed in Annex 5. During the listed days, exchange of water samples and simultaneous sampling could take place (cf. pages 7-8 and Annex 11 of FLEX Info 3).

5. Supplement to FLEX Plankton Studies Workshop Report

A supplement to the Report of the FLEX Plankton Studies Workshop at Aberdeen has been circulated by Mr. J.A.Adams. A list of the contents and of the addressees is given in Annex 6.

6. Weather reports "OBS" De Bilt

Mr. M.P. Visser, De Bilt, writes in a letter of February 26 that, as a result of new regulations on frequencies and times for radio communications, the following has to be added to the schedule distributed earlier (Annex 15/5 of FLEX Info 3) about Scheveningen Radio.

a. From February 1st 1976 it is possible for ships working in A3 (telephony) to call PCH on emergency frequency 2182 kc to get an appointment for another free channel.

b. For ships working in A1 (telegraphy) new regulations are developped, given in Annex 7.

Please inform skippers and wireless-operators of these possibilities.

7. FLEX Communication System

A proposal on real-time and near-real-time data exchange during FLEX is enclosed as a separate supplement. It is a compromise between earlier suggestions of G. Becker/ K. Huber and J.H. Steele/J.A. Adams and, as I hope, it is acceptable now to all FLEX participants. A sufficient number of "Radio Message Information" forms will be sent to all FLEX Chief Scientists. Please, make your own copies of the FLEX-Box Grid for the production of daily synoptic maps of special parameters.

Annexes

1. List of FLEX 76 Ships

2. Proposal for Cruise I of R.V. FRIEDRICH HEINCKE (by G. Wegner).

3. Cruise programmes for RRS CHALLENGER and RRS JOHN MURRAY (by R.H. Bruce & R. Williams).

4. Tentative cruise schedule for R.V. Knorr Cruise 54 (by D.W. Spencer).

5. Intercalibration Schedule

6. Supplement to the Report of the FLEX Plankton Studies Workshop at Aberdeen (edited by J.A. Adams): List of contents and addressees.

7. New regulations for Weather Reports "OBS" De Bilt (by M.P. Visser)

8. Addresses of FLEX 76 Chief Scientists and Co-ordinators

Supplement:

FLEX Information System (Proposal)

with

Forms and Encoding Instructions for "Radio Message Information 'FLEX 76'"

FLEX 76: List of Ships

CALL SIGN	SHIP	CRUISE SCHEDULE (PORT-TO-PORT DATES)	CHIEF SCIENTIST	TRANSMITTER FREQUENCIES	RECEIVER FREQUENCIES
DBAW	VICTOR HENSEN	22 March - 1 April 31 May - 11 June	Gaertner		
DBBH	METEOR	22 March - 15 April 22 April - 18 May 21 May - 16 June	Mittelstadt Koltermann Prahm	410, 425, 454, 468, 480,500, 512 kHz. All frequencies between 1665 kHz-30 MHz(synthesized). VHF: channels 1-56	All frequencies - tween 100 kHz-3 Hz
DBFB	GAUSS	3-12 and 15-25 March 21 - 29 April 10 - 26 May	Grabert Nauke Weidemann	410, 425, 454, 468, 480,500, 512 kHz. 1665, 1925, 2023, 2049, 2056, 2146, 2153, 2182, 2326,2361, 2396, 2421, 2491, 2541,2569, 3023.5, 3161, 3197, 3363, 3394, 4069.2; 4091.6; 4101.2; 4104.4 kHz. VHF: channels 1-56	All frequencies between 100 kHz-30 MHz
DBFO	ANTON DOHRN	5 April - 7 May	Weidemann	410, 425, 448, 454, 468,480, 500, 512 kHz. 1609, 1621, 2023, 2053, 2056, 2146, 2182, 2226, 2312, 2326, 2421, 2431, 2569, 3161, 3197, 3282, 3363, 3394; 4185, 4206.5; 4231 kHz 3 frequencies each in the ranges of 6, 8, 12, 16,22 MHz. VHF: channels 1-28	all frequencies between 14 - 21 kHz; between 85 kHz-30,3 MHz.
DBFK	FRIEDRICH HEINCKE	12 - 29 April 13 - 25 May 31 May - 11 June	Wegner Kullenberg N.N.		
DBLZ	MAX WALDECK	30 May - 20 June	Sellschopp		
DSCZ	PLANET	20 April - 8 May 10 - 29 May 31 May - 19 June	Schirmer Sellschopp Schunk	"all frequencies"	"all frequencies"
GMNH	JOHN MURRAY	2 - 13 April 15 - 30 April	Williams Bruce	2241, 2246, 2310 kHz	2241, 2246, 2310 kHz Multichannel VHF radio (constant listening watch on channel 16)
GNAM	CIROLANA	21 April - 14 May	Ramster	Choice of channels available	(Call frequencies: MW 2182 kHz; VHF-channel 16)
GPIU	CHALLENGER	16 - 24 March	Bruce	2241, 2246, 2310 kHz	2241, 2246, 2310 kHz (Call frequencies: MW: 2182 kHz; VHF-channel: 16)
KCEJ	KNORR	5 May - 4 June (7-11, 13-16, 20-24, 26-30 May in FLEX Box)	Spencer	see attached listing	see attached listing
MLBG	EXPLORER	11 - 24 May 25 May - 7 June	Steele Adams	2056, 2431 kHz; 157.75 MHz	2056, 2431 kHz; 157.75 MHz
ORGQ	MECHELEN	20 March - 15 June (20-27 March; 30 March-6 April; 9-16, 21-28 April; 1-8, 11-18, 21-28 May; 1-7, 10-15 June)	Picard (20.3.-16.4.) Pichot (21.4.-18.5.) Picard (21.5.-15.6.)	H-F 1.5 - 24 MHz. VHF channels 8-28	H-F 1.5 - 24 MHz. VHF channels 8-28
ORGW	NIEUWPOORT	1 - 29 May (1-8, 11-18, 21-30 May)	N.N.	H-F 1.5 - 24 MHz. VHF channels 8-28	H-F 1.5 - 24 MHz. VHF channels 8-28
PCWH	AURELIA	4 April - 6 May 14 - 24 June	Gieskes Fransz	2049; 2056; 2182; 2201; 2316; 2331; 2366; 2391; 2406; 4110.8 kHz. VHF channels 1-28	2056; 2182; 2201; 2331; 2366; 4110.8; 2656 kHz
SEPI	ARGOS	22 March - 8 April (at times)	Svansson	1474, 2037, 2049, 2056, 2182, 2206, 2216, 2221, 2489, 2877, 3185, 3266, 3289, 3296, 3308, 3352 kHz. VHF channels 1-28	(Call frequencie MW: 2182 kHz; VHF-channel 16)
SMJU	SVANIC	8 - 12 June (?)	Kullenberg		VHF channel 16 listening

R.V. KNORR

RADIOTELEGRAPH CONTROL UNIT (CW) FCC FREQUENCIES
SYMBOLS C5, C8, L46. TRANSMITTING FREQS. IN KC:

410	12555 - C
425	12568.5
444	12642
448	16740 - C
454	16758
468	16856
480	22260 - C
500 - C	22275
2091	22340
2092.5 - C	
2105.25	
4185 - C	
4189.5	
4214	
6277.5	C = Calling Freq.
6284.25	
6321	
8370 - C	
8379	
8428	

Radiotelephone Unit 2-9MC AM

Send KC	Receive KC	
2182	2182	Call & Distress
2638	2638	Ship-Ship
2738	2738	Ship-Ship
2670	2670	USCG
2252	2252	Navy
2792	2792	Navy
2406	2506	Boston
2198	2590	NY
2142	2538	Norfolk
2390	2566	Charleston
2031.5	2490	Miami
2134	2580	Galveston
2009	2506	St. Thomas IV
2366	2450	Boston
4104.4	4408.4	NY
4123.5	4428.6	Miami
8223.6	8773.6	NY
8261.9	8811.9	NY

Radiotelephone SSB Freqs.

2096.5
4139.5
8281.2
12421
16565
22094.5

UPPER SIDEBAND A3J
Oceanographic Frequencies

VHF Radiotelephone F3 Emission

FCC Designated Channels 1 thru 28 plus 7A 18A 19A

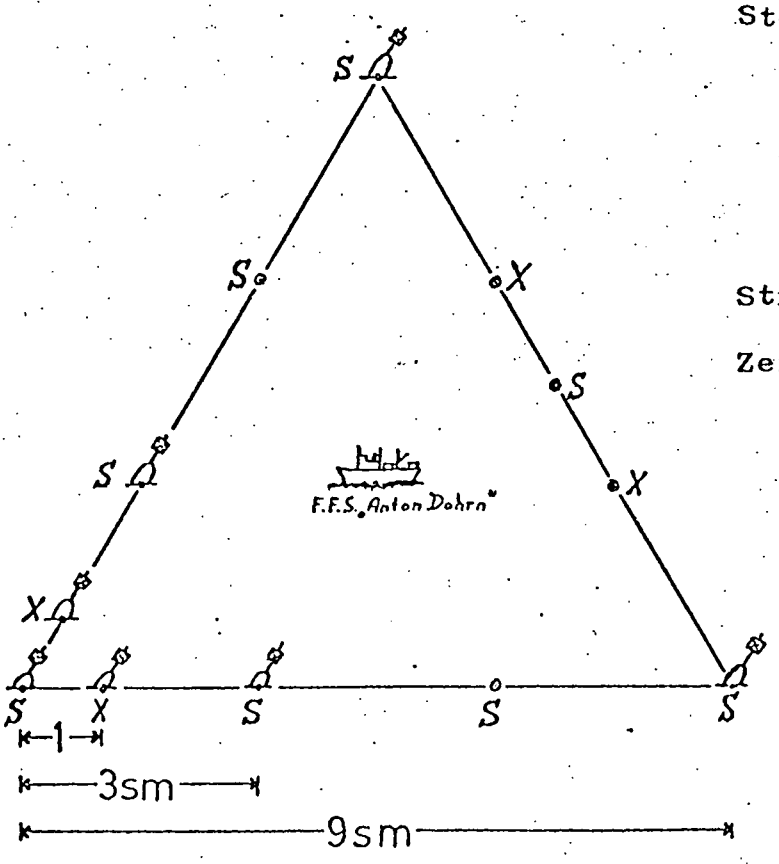
G. Wegner
H. Weidemann
M. Gillbricht

25.2.1976

FLEX '76

Fahrtprogramm des F.K. "Friedrich Heincke"
vom 12. 4. bis 29. 4. 1976

Der F.K. "Friedrich Heincke" nimmt mit einem ersten Fahrtabschnitt vom 12. 4. bis zum 29. 4. 1976 am Fladengrund-Experiment teil. Während dieses Zeitraums sollen in enger Zusammenarbeit mit dem F.F.S. "Anton Dohrn" Informationen über die zeitliche horizontale und vertikale Veränderung von Temperatur, Salzgehalt, Nährstoffen und Plankton gesammelt werden. Dazu sind um das schon in der "Flexbox" arbeitende, mit einer markierten Wassermasse treibende F.F.S. "Anton Dohrn" 7 Driftbojen in Form eines gleichseitigen Dreiecks mit 9 sm Seitenlänge auszulegen. Die daraus resultierende Anfangsverteilung der abzulaufenden unterschiedlichen Positionen zeigt nachfolgende Skizze :



Stationen pro Umlauf:

S 8 hydrogr. Serien mit BT (T,S,Plankton,Nährst.)

X 4 X-BT

Strecke pro Umlauf: ca. 30 sm

Zeit pro Umlauf: ca. 7-8 h

Es ist geplant, das sich mit Wind und Strom verändernde "Dreieck" insgesamt 20 bis 25 mal zu umlaufen, wobei durch wiederholtes Bojenversetzen die Ausgangsform ungefähr beibehalten werden soll. Stündliche Bestimmungen der Driftpositionen erfolgen zusätzlich von "Anton Dohrn" aus.

Um dieses umfangreiche Programm ohne Unterbrechungen durchführen zu können (Ausnahme: Wassernehmen s.u.), werden 5 Wissenschaftler benötigt (s.unten: Fahrtteilnehmer und Raumverteilung).

Als Arbeitsräume werden benutzt :
Mehrzweck-, Mikrobiologie- und Chemielabor.

Termine :

Beladen	Montag, den 12. 4. 76,	09.00 Uhr	Cuxhaven
Auslaufen	Montag, den 12. 4. 76,	13.00 Uhr	Cuxhaven
Ankunft Arbeitsgebiet	Mittwoch, den 14. 4. 76,	ca. 08.00 Uhr	
Ablaufen	Dienstag, den 27. 4. 76,	ca. 14.00 Uhr	
Einlaufen	Donnerstag, den 29. 4. 76,	09.00 Uhr	Cuxhaven
Entladen	Donnerstag, den 29. 4. 76,	10.00 Uhr	Cuxhaven

Abhängig von der Wettersituation und dem Arbeitsablauf ist für die Zeit um den 20. 4. eine etwa 30stündige Unterbrechung des Programms zum Wassernehmen in Peterhead geplant.

Fahrtteilnehmer und Raumverteilung

Mangelsdorf, P.,	techn.Ang.	BAH,	Chemie-Labor	hint.Wiss.Kammer
N.N.	Stud.	Uni Kiel,	Mehrzweck- u. Mikro.-L.	vord.Wiss.Kammer
N.N.	Stud.	Uni Kiel		vord.Wiss.Kammer
N.N.		DHI	" "	Fahrtl.Kammer
Wegner, G.	Wiss.Ang.	DHI	" "	Fahrtl.Kammer

Am Vormittag des 27. 4. 76 werden 2 Herren vom Institut für Meereskunde an der Universität Kiel auf See vom W.F.S. "Planet" auf "Friedrich Heincke" übersteigen, um mit nach Cuxhaven zu fahren.

VESSEL — RRS CHALLENGER (RVB Cruise 4B/76)

CRUISE PERIOD — 16-24 March 1976

PERSONNEL

IMER, Edinburgh:
R H Bruce, SSO (Senior Scientist)
D B Hollis, HSO
A W G John, HSO
IOS, Bidston:
R Palin, SO

ITINERARY

The starting date and duration of cruise 4B/76 depends on the finishing date (14-19 March) of the previous cruise 4A/76.

8-12 March	1st van load of equipment to Aberdeen.
Fri 12 March	Message from RRS CHALLENGER to IMER (Edinburgh) giving progress report on cruise 4A/76 and ETA Aberdeen.
Sun 14	Earliest date for completion of 4A/76 and docking in Aberdeen. R H Bruce, D B Hollis, and equipment on standby in Edinburgh ready to travel by van to Aberdeen. A W G John on standby in Plymouth ready to travel by public transport to Aberdeen.
Mon 15	Earliest date for loading and testing equipment on ship. Further message from RRS CHALLENGER giving ETA Aberdeen.
Tues 16 (early am)	Earliest date for sailing from Aberdeen to start cruise 4B/76.
Fri 19	Latest date for completion of 4A/76 and docking in Aberdeen.
Sun 21 (early am)	Latest date for sailing from Aberdeen to start 4B/76. Carry out survey programme detailed below on passage to and from and within the FLEX square. The location of the square is shown in Fig. 1 and the planned survey grid and station positions are given in Fig. 2. (A table giving precise coordinates of the grid and stations, allowing for the presence of oil-rigs, JONSDAP moorings and other hazards, is being prepared and will be appended later.)
Tues 23 (late pm)	Terminate survey operations in FLEX square.
Wed 24	Dock Aberdeen.
Thurs 25	Unload equipment; store some equipment in Aberdeen; remainder of IMER equipment and staff return to Edinburgh by van.

The duration of cruise 4B/76 will be between 4 and 9 days, depending on the completion date of 4A/76. The following programme will be pursued as long as time permits. (The times have been estimated assuming early sailing on Day 1, good/

good weather and no delays. The programme therefore represents the maximum likely to be achieved.)

Day 1	01.00	Sail from Aberdeen
		Start horizontal profiling equipment and meteorological observations.
		Proceed towards FLEX square along IN-OUT line ILSW at maximum cruising speed (assumed 10 knots)
		Start towing UOR when depth exceeds 50m.
	17.00	Arrive Station 9 (Centre of FLEX square)
		Two N.I.O water-bottle casts (9 depths).
	18.00	LHPR oblique haul.
		HSLE oblique haul.
	19.00	Complete Station 9
		Proceed towards Station 1 towing UOR at 10 knots
	23.00	Arrive Station 1 (S.W. corner of FLEX square)
		N.I.O water-bottle cast.
Day 2	00.00	Start UOR grid (at 10 knots)
		N.I.O water-bottle casts at Stations 2-8
Day 3	23.00	Complete UOR grid and Station 8
		Proceed towards central station towing UOR.
Day 4	03.00	Arrive Station 9
		Two N.I.O water-bottle casts.
		LHPR oblique haul.
		HSLE oblique haul.
	05.00	Complete Station 9
		Proceed towards Station 1 towing UOR
	09.00	Arrive Station 1
		Start 2nd pass of UOR grid and Stations 1-8.
Day 6	09.00	Complete 2nd pass
		Proceed towards central station.
	15.00	Complete 3rd working of Station 9
	19.00	Start 3rd pass of UOR grid and Stations 1-8.
Day 8	19.00	Complete 3rd pass
		Proceed towards central station.
Day 9	01.00	Complete 4th working of Station 9
		Proceed towards Aberdeen towing UOR at 10 knots along IN-OUT line ILSW.
		Recover UOR when depth decreases to 50m.
		Stop horizontal profiling equipment and meteorological observations.
	17.00	Dock Aberdeen

OBJECTIVES

The cruise has two main objectives:

1. To describe the horizontal variability of the physical, chemical and biological processes over the FLEX square (see Fig. 2) in the "pre-bloom" period.

2. To describe the vertical variability of the physical, chemical and biological processes at stations near the margin and at the centre of the FLEX square in the "pre-bloom" period.

There are two subsidiary objectives:

3./

3. To make physical and chemical measurements and to sample the plankton along the IN-OUT line ILSW across the Orkney-Shetland inflow.

4. To contribute to the collection of meteorological data as requested in Annex III of the report on the JONSDAP 76 Meeting at Aberdeen.

PROCEDURES AND METHODS

1. The first objective will be met by making one or more quasi-synoptic surveys of the FLEX square. Each survey will consist of one pass over a 720km grid consisting of seven 90km N-S legs, 15km. apart.(Fig. 2). Each pass will take about 2 days at 10 knots, and the following measurements and samples will be taken:

1.1 Temperature and salinity at 2m depth using IOS (Bidston)'s surface sampling CTD system with a pumped sea-water supply.

1.2 Temperature, salinity/depth profiles as the UOR undulates between 5 and 60m depth with a wavelength of 2.5km.

1.3 '5km' samples of 'net' phytoplankton and zooplankton integrated over the depth range of the UOR, using 300µm mesh.

2. The second objective will be met by working stations 1-9, each station being visited at least once, at 3-4 day intervals, between or during passes over the grid.

The following measurements will be taken at <u>every station</u>:

2.1 Temperature, and salinity from water samples taken at 9 depths (3, 10, 20, 30, 40, 60, 80, 100m and near bottom).

The following samples will be taken at <u>Stations 1, 3, 5, 7 and 9</u>:

2.2. Water samples from the 9 depths in (2.1) for nitrate, nitrite, phosphate, silicate, chlorophyll <u>a</u>, phytoplankton cell counts and microzooplankton counts (all analysed ashore).

The following samples will be taken from the <u>central station only</u>:

2.3 Micro- and macrozooplankton from near-bottom to surface by oblique hauls with the High Speed Loch Ewe (HSLE) double net sampler (68 and 250µm mesh) to determine C/N values, length/weigth ratios and calorific values.

2.4 Zooplankton from near-bottom to surface by oblique hauls with the Longhurst Hardy Plankton Recorder (LHPR)/

(LHPR) with 5m depth resolution.(280μm mesh).

3. The third objective will be met by taking measurements as in 1.1 - 1.3 while on passage between Aberdeen and the FLEX square.

4. The fourth objective will be met by:

4.1 Taking the following observations at hourly intervals whenever possible throughout the cruise:

Position	±1nm
Wind speed and direction	±1km, ±1°
Air temperature	±0.1C°
Humidity (or wet bulb temperature)	±1%(±0.1C°)
Sea surface temperature	±0.1C°
Pressure	±0.1mb
Cloudiness	
Sea State	

4.2 Transmitting 6 hourly radio messages of the above observations taken at 0, 6, 12 and 18.00 GMT via Radio Scheveningen to Meteo de Bilt.

EQUIPMENT REQUIRED

a) Supplied by RVB

6 N10 water bottles and messengers
12 reversing thermometers, protected, range at least 0-15°C, with calibration certificates.
1 XBT system (launcher, recorder, 3 doz. probes)
1 Deep freeze unit to maintain -20°C
1 Precision depth recorder (0-200m)
2 Dahn buoys with radar reflectors, cables and anchor weights for laying markers in up to 150m depth
1 Helle directional antenna (for locating Helle 27kHz pingers)
Meteorological Log Sheets and Radio Message Encoding Sheets

b) Supplied by IOS, Bidston

1 Surface-sampling CTD system complete with pumped sea-water supply, real-time analogue display on chart recorder, digital data logger and accessories

c) Supplied by DAFS, Aberdeen

1 High Speed Loch Ewe sampling system and accessories

d) Supplied by IMER, Edinburgh

2 Undulating Oceanographic Recorders with support gear
2 Longhurst Hardy Plankton Recorders with support gear
1 Continuous Plankton Recorder (fitted with MATR package) and support gear
Bench Salimometer and Standard Sea water
Salinity sample bottles
Nutrient vials (glass and plastic)
Filtering equipment, vacuum pump, storage jars
Distilled water; Formaldehyde

Date: 16.2.76

INSTITUTE FOR MARINE ENVIRONMENTAL RESEARCH — CRUISE PROGRAMME IMER/FLEX/2/76

VESSEL — RRS JOHN MURRAY (RVB Cruise No 4A/76)

CRUISE PERIOD — 2-13 April 1976

PERSONNEL

IMER, Edinburgh
R.Williams, PSO (Senior Scientist)
J.Aiken, SSO
W.G.Lonie, PTO IV
R.Marak (United States National Marine Fisheries Service)
DAFS, Aberdeen
I.E.Baird, SSO
E.W.Henderson, HSO
R.Payne, HSO
D.V.Conway, SO

ITINERARY

A planned cruise track with station positions are shown in Fig. 2 (A table giving precise co-ordinates of the grid and stations, allowing for the presence of oil rigs, JONSDAP moorings and other hazards, is being prepared by DAFS and will be appended later).

The estimated times given below assume an early sailing, late docking, good weather and no delays. The itinerary therefore represents the maximum likely to be achieved.

31 March	IMER and NMFS staff and equipment transported to Aberdeen, load equipment aboard.
1 April	Load DAFS equipment aboard. Personnel sign on. Prepare and test equipment.
2 April (early am)	Sail from Aberdeen Start horizontal profiling equipment and meteorological observations. Proceed towards the SW corner of the FLEX square along the IN-OUT line ILSW at maximum cruising speed. Start UOR and CPR tows when depth greater than 50m.
pm	Arrive Station 1 Lay moorings for sediment traps. Two N10 water-bottle casts (14 depths).
3 April (early am)	Start UOR and CPR grid (10 kts.) Two N10 water-bottle casts at each of Stations 2-8.
4 April (late pm)	Complete UOR and CPR grid and Station 8.
5 April	Proceed towards central Station 9 (centre of the FLEX square) towing UOR and CPR. Arrive Station 9 Lay moorings for sediment traps. Two N10 water-bottle casts, HSLE oblique net haul.
06.00	LHPR oblique haul. Large volume water samples. Proceed towards Station 1 towing UOR and CPR.
12.00	Arrive Station 1 Uplift and relay sediment traps. Two N10 water-bottle casts.
15.00/	

15.00	Start HSLE grid (at 5 kts.)
	Two water-bottle casts at each of Stations 2-8
9 April	Complete HSLE grid and Station 8
(early am)	Proceed towards central Station 9
09.00	Arrive Station 9 and work as before
12.00	LHPR oblique haul
	Proceed towards Station 1
18.00	Arrive Station 1
	Uplift and relay sediment traps
	Two N10 water-bottle casts
21.00	Start UOR and CPR grid
	Two water-bottle casts at each of Stations 2-8
11 April	Complete UOR and CPR grid and Station 8
(late pm)	Proceed towards central Station 9 towing UOR and CPR
12 April	Arrive Station 9
	Work Station as before and uplift and relay sediment traps
06.00	^{14}C Production experiment in situ
12.00	LHPR oblique haul
	Proceed towards Station 1 towing UOR and CPR
17.00	Arrive Station 1
	Uplift sediment traps
	Two N10 water-bottle casts
20.00	Proceed towards Aberdeen along IN-OUT leg ILSW towing UOR and CPR
	Complete all operations, UOR and CPR, profiling equipment and meteorological observations when depth of water is less than 50m
13 April	Dock Aberdeen
14 April	Unload equipment. Discuss operations with personnel for next cruise.
	IMER and NMFS Staff return to Edinburgh

EQUIPMENT REQUIRED

a) Supplied by RVB

XBT system complete - with 3 doz. probes
Precision depth recorder (0-200m)
Hull mounted thermistor
8 N10 water bottles together with 16 protected thermometers (range at least 5-15°C), calibration certificates and 9 messengers
1 large deep freezer (-20°C)
1 domestic type refrigerator
2 Dhan buoys with radar reflectors, cables and anchor weights for laying markers in up to 150m depth
Helle directional antenna (for locating Helle 27kHz pinger)

b) Supplied by DAFS, Aberdeen

Turner Fluorimeter
Autoanalyser
Thermosalinograph
Sediment traps together with two complete moorings
High Speed Loch Ewe sampling system
Large volume water bottles
^{14}C incubation equipment
Filtering equipment, vacuum pumps, storage jars, large containers of distilled water, etc.

c)/

c) Supplied by IMER, Edinburgh

Continuous Plankton Recorder with support gear
Undulating Oceanographic Recorder with support gear and NMFS-UOR
Longhurst Hardy Plankton Recorder (2 systems) with support gear
Nutrient vials (glass and plastic), large containers of Formaldehyde

OBJECTIVES

The cruise has three main objectives:

1) To describe the horizontal variability of the physical, chemical and biological processes over the FLEX square (see Fig. 2) throughout the cruise period.

2) To describe the vertical variability of the physical, chemical and biological processes at stations near the margin and at the centre of the FLEX square throughout the cruise period.

3) To measure the rates of selected processes in the FLEX square during the period of the cruise.

There are four subsidiary objectives:

4) To make physical and chemical measurements and to sample the plankton along the IN-OUT line ILSW across the Orkney and Shetland inflow.

5) To take comparative tows of the UOR and HSLE net and of the LHPR and Weikert's (University of Hamburg) opening and closing net.

6) To contribute to the collection of meteorological data as requested in Annex III of the report on the JONSDAP 76 meeting at Aberdeen.

7) To provide ground truth data for the correct interpretation and calibration of the radiation data acquired during the aerial survey programme.

PROCEDURES AND METHODS

1. The first objective will be met by making quasi-synoptic surveys of the FLEX square at 3-4 day intervals. Each survey will consist of one pass over a 720km grid consisting of seven 90km N-S legs, 15km apart (Fig. 2). Alternate passes will be made using the Undulating Oceanographic Recorder (UOR) and the Continuous Plankton Recorder (CPR), taking approximately 2 days at 10 knots, and the High Speed Loch Ewe (HSLE) sampler, approximately taking 4 days at 5 knots.

During each UOR-CPR pass over the grid the following measurements will be made:

1.1 Temperature, salinity, *in vivo* Chlorophyll *a* and nitrate at 3m depth using the ship's non-toxic pumped sea-water supply (DAFS).

1.2/

1.2 Samples for Chlorophyll a and phaeophytin (for calibration, 2 per hour), particulate organic carbon and nitrogen (4 per day), phytoplankton cell counts (Gillbricht, 10 per day), all from the pumped sea-water supply (DAFS).

1.3 Temperature at 10m by instruments carried in the CPR (IMER).

1.4 Temperature, salinity/depth profiles as the UOR undulates between 5 and 80m depth with a wavelength of 2.5km (IMER).

1.5 '16km' samples of 'net' phytoplankton and zooplankton taken by the CPR at 10m depth, using 300µm mesh (IMER).

1.6 '5km' samples of 'net' phytoplankton and zooplankton integrated over the undulation depth range (5-80m) of the UOR, using 300µm mesh (IMER).

1.7 Meteorological observations as requested in Annex III of the report on the JONSDAP 76 meeting at Aberdeen (IMER).

During each HSLE pass over the grid the following measurements will be made:

1.8 Temperature, salinity, Chlorophyll a and nitrate as in 1.1 (DAFS).

1.9 Samples as in 1.2 (DAFS).

1.10 Micro- and macrozooplankton samples taken by oblique hauls from near-bottom to surface at 5km intervals with the HSLE double net sampler (68µm and 250µm mesh) (DAFS).

2. The second objective will be met by working stations 1-9, each station being visited at 3-4 day intervals between or during passes over the grid.

The following measurements will be taken at every station:

2.1 Temperature, salinity, Chlorophyll a and nitrate (analysed on board); nitrate, nitrite, phosphate, silicate, phytoplankton cell counts and microzooplankton counts (analysed ashore), all from water samples taken at 0, 3, 10, 20, 30, 50, 60, 70, 80, 90, 100, 125m and near-bottom (IMER and DAFS).

The following samples will be taken only at the central station:

2.2 Zooplankton from near-bottom to surface by oblique hauls with the Longhurst Hardy Plankton Recorder (LHPR) with 5m depth resolutions (mesh 280µm) (IMER).

2.3 Micro- and macrozooplankton from near-bottom to surface by oblique hauls with the HSLE to determine C/N values, length/weight ratios and calorific values (IMER).

2.4 Large volume water samples from selected depths for the determination of particulate organic carbon and nitrogen (DAFS).

The following samples will be taken on one occasion at Station 1:

2.5 Large volume water samples, as in 2.4, from three depths (DAFS).

3. The third objective will be met by taking the following measurements:

3.1 Primary productivity ^{14}C, using simulated in situ incubation with 6 light levels, once per day with samples from a marginal station occupied nearest between 06.00 and 12.00 G.M.T. (DAFS).

3.2 As 3.1 on one occasion, during the cruise, with samples from the central station (DAFS).

3.3 Primary productivity ^{14}C using a 6 hour incubation in situ at the central station (DAFS).

3.4 Sedimentation rates from five depths at the centre and S.W. corner (Station 1) of the FLEX square every 3-4 days (DAFS).

4. The fourth objective will be met by taking measurements as in 1.1-1.7 while on passage between Aberdeen and the FLEX square.

5. The fifth objective will be met by taking comparative hauls along the FLEX square diagonal and when J MURRAY and the MECHELEN are on the central station together.

6. The sixth objective will be met by:

6.1 Taking the following observations at hourly intervals whenever possible throughout the cruise

Position	$\pm$ 1nm
Wind speed and direction	$\pm$ 1km, $\pm$ 1°
Air temperature	$\pm$ 0.1°C
Humidity (or wet bulb temperature)	$\pm$ 1% ($\pm$ 0.1°C)
Sea surface temperature	$\pm$ 0.1°C
Pressure	$\pm$ 0.1 mb
Cloudiness	

6.2 Transmitting 6 hourly radio messages of the above observations taken at 0, 6, 12 and 18.00 G.M.T. via Radio Scheveningen to Meteo de Bilt.

7. The seventh objective will be met by:

7.1 Taking, wherever possible, the following samples or measurements during the overflight or, if no overflight occurs, at the day of aircraft operation, around noon.

Physical: Surface temperature (0.1°C)
Depth of visibility by Secchi disc

Biological: Plankton concentration
Particle concentration
Particle dry weight
Chlorophyll

Weather: As for objective 6

7.2 File reports on the above measurements to Institut fur Hydrobiologie und Fischereiwissenschaft Universitat Hamburg, Palmaille 55, D-2000 Hamburg 50.

Date: 3 March 1976
Prepared by: R Williams and R H Bruce
Approved by: R S Glover

VESSEL — RRS JOHN MURRAY (RVB Cruise No. 4B/76)

CRUISE PROGRAMME — 15-30 April, 1976

PERSONNEL

IMER, Edinburgh
R H Bruce, SSO (Senior Scientist)
G W Evans, HSO
D B Hollis, HSO
G Wood
DAFS, Aberdeen
J M Davies, SSO
D M Finlayson, SSO
I M Davies, SO
S J Hay, SO

ITINERARY

A planned cruise track with station positions are shown in Fig. 2.
The estimated times given below assume an early sailing, late docking, good weather and no delays. The itinerary therefore represents the maximum likely to be achieved.

14 April (early am) IMER and NMFS personnel and equipment depart Edinburgh for Aberdeen
pm DAFS, IMER and NMFS personnel sign on and discuss operations with scientists from previous cruise.
Load DAFS and IMER equipment.
Test and prepare equipment.

15 April (early am) Sail from Aberdeen
Start horizontal profiling equipment and meteorological observations.
Proceed towards centre of FLEX square along IN-OUT line ILSW at maximum cruising speed (assumed 10 knots).
Start UOR and CPR tows when depth greater than 50m.
pm Arrive Station 9 (centre of FLEX square)
Two N10 water-bottle casts.
18.00 LHPR oblique haul.
HSLE oblique haul.
Large volume water samples.
Lay moorings for sediment traps.

16 April Arrive Station 1 (S.W. corner of FLEX square)
01.00 Two N10 water-bottle casts.
Large volume water samples.
Lay mooring for sediment traps.
04.00 Start HSLE grid (at 5 knots)
Two N10 water-bottle casts at each of Stations 2-8.

19 April Complete HSLE grid and Station 8
pm Proceed towards central station, towing UOR and CPR at 10 knots.
18.00 Arrive Station 9 and work as before.
LHPR oblique haul.
Uplift and re-lay sediment traps.
22.00 Complete Station 9
Reciprocal tows of HSLE and UOR along diagonal for inter-comparison.

20 April/

20 April	Arrive Station 1
06.00	Two N10 water-bottle casts.
	Uplift and re-lay sediment traps.
09.00	Start UOR/CPR grid (at 10 knots)
	Two N10 water-bottle casts at Stations 2-8.
22 April	Complete UOR/CPR grid and Station 8
early am	Proceed towards central station still towing UOR and CPR.
12.00	Arrive Station 9 and work as before.
	LHPR oblique haul.
	Uplift and re-lay sediment traps.
16.00	Complete Station 9
	Reciprocal tows of HSLE and UOR along diagonal.
23 April	Arrive Station 1
00.00	Two N10 water-bottles casts .
	Uplift and re-lay sediment traps.
03.00	Start HSLE grid
	Two N10 water-bottle casts at each of Stations 2-8
26 April	Complete HSLE grid and Station 8
	Proceed towards central station towing UOR and CPR.
18.00	Arrive Station 9 and work as before.
	LHPR oblique haul.
	Uplift and re-lay sediment traps.
22.00	Complete Station 9
	Proceed towards S.W. corner towing UOR and CPR
27 April	Arrive Station 1
02.00	Tow N10 water-bottle casts.
	Uplift and re-lay sediment traps.
05.00	Start UOR/CPR grid
	Two N10 water-bottle casts at each of Stations 2-8.
29 April	Complete UOR/CPR grid and Station 8
early am	Proceed towards central station towing UOR and CPR.
07.00	Arrive Station 9 and work as before
	Uplift sediment traps
	LHPR/Weikert's multiple net sampler comparative haul
11.00	LHPR oblique haul.
12.00	Complete Station 9
	Proceed towards S.W. corner towing UOR and CPR.
16.00	Arrive Station 1
	Two N10 water-bottle casts .
	Uplift sediment traps .
19.00	Complete Station 1
	Proceed towards Newcastle towing UOR and CPR while depth greater than 50m.
	Stop continuous profiling equipment and meteorological observations.
30 April	Arrive Newcastle
19.00	
1 May am	Unload equipment.
pm	IMER and NMFS personnel and equipment return to Edinburgh by train or laboratory van .
	DAFS personnel and equipment return to Aberdeen.

EQUIPMENT REQUIRED

a) Supplied by RVB

XBT system complete - with 3 doz. probes
Precision depth recorder (0-200m)
Hull mounted thermistor

8 N10 water-bottles together with 16 protected thermometers (range at least 5-15°C), calibration certificates and 9 messengers
1 large deep freezer (-20°C)
1 domestic type refrigerator
2 Dhan buoys with radar reflectors, cables and anchor weights for laying markers in up to 150m depth
Helle directional antenna (for locating Helle 27kHz pinger)

b) Supplied by DAFS, Aberdeen

Turner Fluorimeter.
Autoanalyser.
Thermosalinograph.
Sediment traps together with two complete moorings.
High Speed Loch Ewe sampling system.
Large volume water bottles.
^{14}C incubation equipment.
Filtering equipment, vacuum pumps, storage jars, large containers of distilled water, etc.

c) Supplied by IMER, Edinburgh

Continuous Plankton Recorder with support gear.
Undulating Oceanographic Recorder with support gear and NMFS-UOR.
Longhurst Hardy Plankton Recorder (2 systems) with support gear.
Nutrient vials (glass and plastic), large containers of Formaldehyde.

OBJECTIVES

The cruise has three main objectives:

1) To describe the horizontal variability of the physical, chemical and biological processes over the FLEX square (see Fig. 2) throughout the cruise period.

2) To describe the vertical variability of the physical, chemical and biological processes at stations near the margin and at the centre of the FLEX square throughout the cruise period.

3) To measure the rates of selected processes in the FLEX square during the period of the cruise.

There are four subsidiary objectives:

4) To make physical and chemical measurements and to sample the plankton along the IN-OUT line ILSW across the Orkney and Shetland inflow.

5) To take comparative tows of the UOR and HSLE net and of the LHPR and Weikert's (University of Hamburg) opening and closing net.

6)/

6) To contribute to the collection of meteorological data as requested in Annex III of the report on the JONSDAP 76 meeting at Aberdeen.

7) To provide ground truth data for the correct interpretation and calibration of the radiation data acquired during the aerial survey programme.

PROCEDURES AND METHODS

1. The first objective will be met by making quasi-synoptic surveys of the FLEX square at 3-4 day intervals. Each survey will consist of one pass over a 720km grid consisting of seven 90km N-S legs, 15km apart. Fig. 2. Alternate passes will be made using the Undulating Oceanographic Recorder (UOR) and the Continuous Plankton Recorder (CPR), taking approximately 2 days at 10 knots, and the High Speed Loch Ewe (HSLE) sampler, approximately taking 4 days at 5 knots.

During each UOR-CPR pass over the grid the following measurements will be made:

1.1 Temperature, salinity, in vivo Chlorophyll a and nitrate at 3m depth using the ship's non-toxic pumped sea-water supply (DAFS).

1.2 Samples for Chlorophyll a and phaeophytin (for calibration, 2 per hour), particulate organic carbon and nitrogen (4 per day), phytoplankton cell counts (Gillbricht, 10 per day), all from the pumped sea-water supply (DAFS).

1.3 Temperature at 10m by instruments carried in the CPR (IMER).

1.4 Temperature, salinity/depth profiles as the UOR undulates between 5 and 80m depth with a wavelength of 2.5km (IMER).

1.5 '16km' samples of 'net' phytoplankton and zooplankton taken by the CPR at 10m depth, using 300µm mesh (IMER).

1.6 '5km' samples of 'net' phytoplankton and zooplankton integrated over the undulation depth range (5-80m) of the UOR, using 300µm mesh (IMER).

1.7 Meteorological observations as requested in Annex III of the report on the JONSDAP 76 meeting at Aberdeen (IMER).

During each HSLE pass over the grid the following measurements will be made:

1.8 Temperature, salinity, Chlorophyll a and nitrate as in 1.1 (DAFS).

1.9/

1.9 Samples as in 1.2 (DAFS).

1.10 Micro- and macrozooplankton samples taken by oblique hauls from near-bottom to surface at 5km intervals with the HSLE double net sampler (68µm and 250µm mesh) (DAFS).

2. The second objective will be met by working stations 1-9, each station being visited at 3-4 day intervals between or during passes over the grid.

The following measurements will be taken at every station:

2.1 Temperature, salinity, Chlorophyll a and nitrate (analysed on board); nitrate, nitrite, phosophate, silicate, phytoplankton cell counts and microzooplankton counts (analysed ashore), all from water samples taken at 0, 3, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 125m and near-bottom (IMER and DAFS).

The following samples will be taken only at the central station:

2.2 Zooplankton from near-bottom to surface by oblique hauls with the Longhurst Hardy Plankton Recorder (LHPR) with 5m depth resolutions (mesh 280µm) (IMER).

2.3 Micro- and macrozooplankton from near-bottom to surface by oblique hauls with the HSLE to determine C/N values, length/weight ratios and calorific values (IMER).

2.4 Large volume water samples from selected depths for the determination of particulate organic carbon and nigrogen (DAFS).

The following samples will be taken on one occasion when the nitrogen productivity is done (3.3).

2.5 Large volume water samples, as in 2.4, from three depths (DAFS).

3. The third objective will be met by taking the following measurements:

3.1 Primary productivity ^{14}C, using simulated in situ incubation with 6 light levels, once per day with samples from a marginal station occupied nearest between 06.00 and 12.00 G.M.T. (DAFS).

3.2 As 3.1 on one occasion, during the cruise, with samples from the central station (DAFS).

3.3 Nitrogen production, using simulated in situ incubator with 3 light levels, on one occasion from one of the nine stations on the grid (DAFS).

3.4/

3.4 Nitrogen uptake kinetics 1 per grid from a selected depth at the central station (DAFS).

3.5 Sedimentation rates from five depths at the centre and S.W. corner (Station 1) of the FLEX square every 3-4 days (DAFS).

4. The fourth objective will be met by taking measurements as in 1.1-1.7 while on passage between Aberdeen and the FLEX square.

5. The fifth objective will be met by taking comparative hauls along the FLEX square diagonal and when J MURRAY and the MECHELEN are on the central station together.

6. The sixth objective will be met by:

6.1 Taking the following observations at hourly intervals whenever possible throughout the cruise.

Position	± 1nm
Wind speed and direction	± 1km, ± 1°
Air temperature	± 0.1°C
Humidity (or wet bulb temperature)	± 1% (± 0.1°C)
Sea surface temperature	± 0.1°C
Pressure	± 0.1mb
Cloudiness	
Sea state	

6.2 Transmitting 6 hourly radio messages of the above observations taken at 0, 6, 12 and 18.00 G.M.T. via Radio Scheveningen to Meteo de Bilt.

7. The seventh objective will be met by:

7.1 Taking, wherever possible, the following sample or measurements during the overflight or, if no overflight occurs at the day of aircraft operation, around noon.

Physical: Surface temperature (0.1°C)
Depth of visibility by Secchi disc.

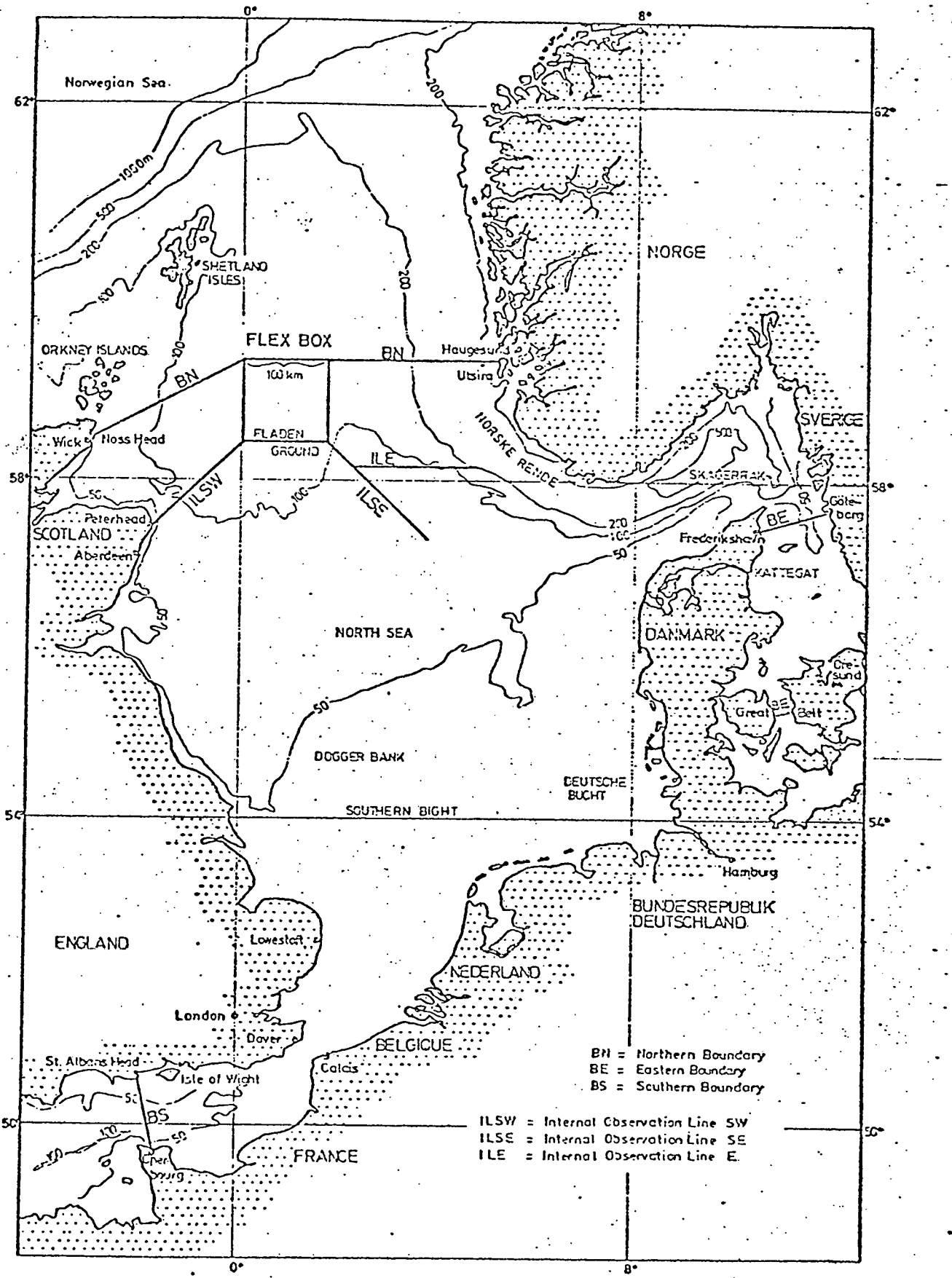
Biological: Plankton concentration
Particle concentration
Particle dry weight
Chlorophyll

Weather: as for objective 6.

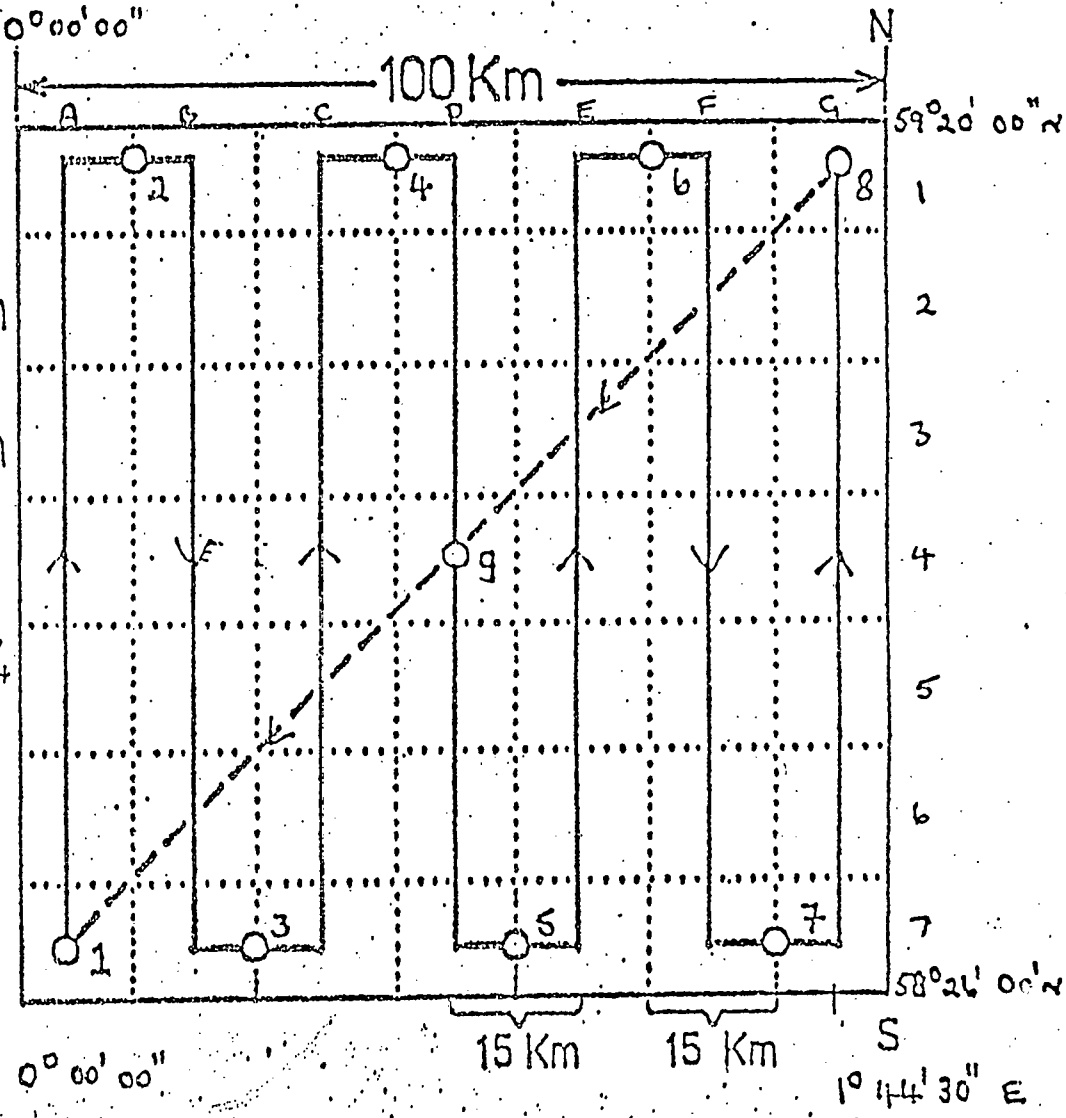
7.2 File reports on the above measurements to Institut fur Hydrobiologie und Fischereiwissenschaft,

Date: 3 March 1976
Prepared by: R H Bruce and R Williams
Approved by: R S Glover

Fig.1 Observation Lines and Areas in JONSDAP 76



PROPOSED CRUISE TRACK — FLEX 76



Cruise track – 720 Km

CT + Diagonal – 850 Km

No of samples/
/CT (1sample/5Km) – 144

O – Stations 1–9

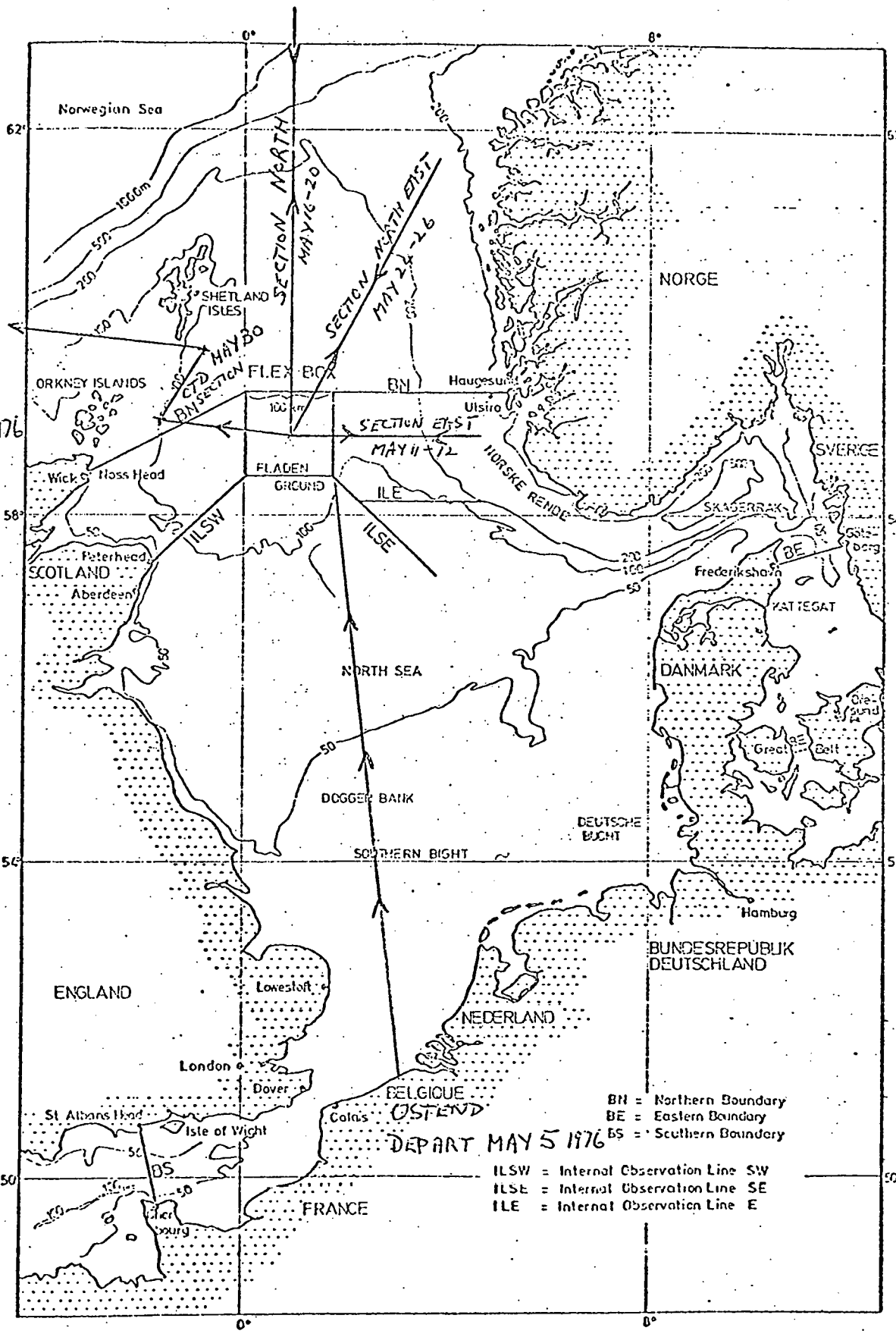
C

TENTATIVE CRUISE SCHEDULE R/V KNORR CRUISE 54
MAY 5 - JUNE 4, 1976
OSTEND, BELGIUM TO REYKJAVIK, ICELAND

May 5	Depart Ostend (possibly Portsmouth or Southampton)
May 5 - May 7	Transect to FLEX Box; Coring
May 7 - May 11	FLEX Box I; CTD Sections, Large Volume Water Sampling, Hydrostations; Coring, Plankton Tows
May 11 - May 13	Section East; CTD, Hydrostations, Coring, Plankton Tows, Large Volume Water Sampling
May 13 - May 16	FLEX Box II; work as FLEX Box I
May 17 - May 20	Section North; work as Section East
May 20 - May 24	FLEX Box III; work as FLEX Box I
May 24 - May 26	Section Northeast; work as Section East
May 26 - May 30	FLEX Box IV; work as FLEX Box I
May 30 - June 4	Transect to Iceland; CTD's Hydrostations, Large Volume Sampling, Coring in Faroes-Scotland Overflow and North Atlantic
June 4	Arrive Reykjavik

HYDRO STATION WORK

1) Hydrocast CTD Rosette 10 bottles) Nutrients, oxygen, particulate
2) Hydrocast Wire 5 bottles) matter, tritium-He^3
3) Box Core (Johnson)
4) Core (Bowen)
5) Plankton Tows (Bowen)
6) Plankton Tows (Spencer)
7) Large Volume Casts (Bowen) Sr^{90}, Cs^{137}, Transuranics
8) Large Volume Casts (Spencer) Pb^{210}, Po^{210}
9) Radium - 228, 226 Casts
10) Insitu Filtration
11) Plankton Tows, etc. (German Scientists)



BN = Northern Boundary
BE = Eastern Boundary
BS = Southern Boundary
ILSW = Internal Observation Line SW
ILSE = Internal Observation Line SE
ILE = Internal Observation Line E

TO REYKJAVIK ARRIVE JUNE 4 1976

DEPART MAY 5 1976

TENTATIVE CRUISE PLAN R/V KNORR

MAY 5 - JUNE 4 1976

Intercalibration Schedule

It is proposed that FLEX ships come together, for the purpose of intercalibration, in the vicinity of R.V. METEOR (or R.V. ANTON DOHRN, on 25 April) at 12.00 GMT on the following days:

31 March	MECHELEN METEOR VICTOR HENSEN ARGOS
12 April	MECHELEN METEOR ANTON DOHRN JOHN MURRAY
25 April	MECHELEN METEOR ANTON DOHRN GAUSS FRIEDRICH HEINCKE PLANET JOHN MURRAY
4 May	MECHELEN NIEUWPOORT METEOR ANTON DOHRN PLANET CIROLANA AURELIA
16 May	MECHELEN NIEUWPOORT METEOR GAUSS FRIEDRICH HEINCKE PLANET EXPLORER KNORR
3 June	MECHELEN METEOR FRIEDRICH HEINCKE PLANET MAX WALDECK VICTOR HENSEN EXPLORER

SUPPLEMENT TO THE REPORT OF THE FLEX PLANKTON STUDIES WORKSHOP

DETAILS OF TECHNIQUES ETC.

Edited by

J. A. Adams

CONTENTS

Circulation:

M. Bourgoin, H. Duchrow, W.W. Gieskes, M. Gillbricht, E. Hagmeier, J.H. Hecq, G. Kullenberg, M. Mork, G. Pichot, P. Polk, J.W. Ramster, D. Spencer, J.H. Steele, A. Svansson, K.J. Trahms, M. Visser, H. Weidemann, R. Williams

FLEX 76: Addresses of Chief Scientists and Co-ordinators

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Co-ordinator of Edinburgh Group	Robinson, G.A.	Institute for Marine Environmental Research (IMER) Oceanographic Laboratory, 78 Craighall Road Edinburgh EH6 4RQ Scotland Telephone: 552 4259
JOHN MURRAY I Chief Scientist	Williams, R.	
JOHN MURRAY II and CHALLENGER Chief Scientist	Bruce, R.H., Dr.	
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UNITED STATES

National Contact and KNORR Chief Scientist	Spencer, D.W., Prof.Dr.	Woods Hole Oceanographic Institution Woods Hole, Mass. 02543 Telephone: 548 1400

REGION VI - EUROPE

and type of station. et type de ation. (Date)	Country Pays	Location Emplacement	Call sign Indicatif d'appel	Class of emission Classe de l'émission	Receiving frequencies / Fréquences de réception (kHz)		Transmitting frequencies Fréquences de transmission (kHz)		Hours of operation (GMT) Heures de vacation (TMG)	Radio adress of Met. Centre	Remarks Remarques
					watch veille	working travail	call appel	working travail			
1	2	3	4	5	6	7	8	9	10	11	12
					ZONE VI-A (Atlantic/Atlantique)						
eningen (a)	Netherlands/	52°06'N(	PCH 95	A1/F1 [1]	4178-4187	ships indicate their working frequencies.	4250	4250		METEO	TEMP SHIP
dio	Pays-Bas	04°16'E(	PCH 96	A1/F1 [1]	4178-4187		6404	6404	2)	De Bilt	
-1976)		(	PCH 2	A1	8356-8374		8562	8562	0800-0815 [2]		
		52°10'N(	PCH 3	A1	8356-8374		8622	8622	0800-0815 [2][3]		
		05°50'E(	PCH 4	A1/F1 [1]	8356-8374		8654	8654	0800-0815 [2]		
		(	PCH 5	A1/F1 [1]	12534-12561		12768	12768			
		(	PCH 6	A1	12534-12561		12799,5	12799,5			
		52°06'N	PCH 7	A1	12534-12561		12853,5	12853,5	2)		
		04°16'E									
		52°10'N(	PCH 8	A1	12534-12561		12966	12966			
		05°50'E(	PCH 92	A1/F1 [1]	16712-16748		17007,2	17007,2			
		(	PCH 93	A1	16712-16748		17103,2	17103,2	2)		
		(	PCH 94	A1	16712-16748		17237,6	17237,6			
		52°06'N	PCH 97	A1	22222,5 -		22539	22539			
		04°16'E			22267,5						
		52°10'N	PCH 98	A1/F1 [1]	22222,5 -		22575	22575	2)		
		05°50'E			22267,5						

is transmitter is also available for radio telex working (CCIR standards-see Radio Regulations art. 29A). Ships fitted with such uipment may call directly on the corresponding scanning frequency (R.R. 1062AP/AQ Mar 2 apply). For further particulars refer to e list of coastal stations. The call should be followed by the indication OBS to ensure priority (e.g. PCH de PFQR/OBS). After ansmission of the message acknowledgment of receipt should be requested.

REGION VI - EUROPE

and type of station ct type de tation Date)	Country Pays	Location Emplacement	Call sign Indicatif d'appel	Class of emission / Classe de l'émission	Receiving frequencies Fréquences de réception (kHz)		Transmitting frequencies Fréquences de transmission (kHz)		Hours of operation (GMT) Heures de vacation (TMG)	Radio address of Met. Centre Adresse radio du Centre météorologique	Remarks Remarques
					watch veille	working travail	call appel	working travail			
1	2	3	4	5	6	7	8	9	10	11	12
					ZONE VI-A (Atlantic/Atlantique)						
reningen	Netherlands	52°06'N (	PCH	A1	500	454	461	461	2)5)	METEO	TEMP SHIP
(cont'd)		04°16'E (	-	A3H	2182 4)	2030 or working freq- indicated by ship	1764	1764	0000-0015	De Bilt	
		(							0600-0615		
		(							1200-1215		
		(							1800-1815		
		(	-	A3H	2182 4)	2160 or working freq- indicated by ship	1939	1939	1200-1215		
		(							1800-1815		
		53°24'N	-	A3H	2182 4)	2160 or working freq- indicated by ship	1862	1862			
		06°04'E									

though 0800-0815 GMT is reserved exclusively for ships with OBS-messages calling PCH2, 3 or 4, ships failing to contact PCH thin that period may call any other transmitter in any band open for service. These calls will be handled with priority provided ey bear the suffix "OBS", e.g. PCH92 de PFQR/OBS.

ailable after emission of 0748 GMT - tfclist.

ips calling on 2182 are encouraged to indicate clearly they have an "OBS"-message on hand so as to obtain priority.

rect contact may be made on 454/461 from 0700-2300 GMT.

FLEX Information 5

Distributed by the Project Manager:
Harald Duchrow, Sonderforschungsbereich Meeresforschung (SFB 94)
an der Universität Hamburg,
D-2000 Hamburg 13, Bundesstrasse/Sedanstrasse (Baracke SW)
Telephone: (040) 4123-4236
Telex: 214 732 uni hhd

Hamburg, 1 April 1976

To:
- the JONSDAP 76 Co-ordinators
- the FLEX Chief Scientists [1)]
(names and addresses: see Annex 8 of FLEX Information 4).

1. State of Fladen Ground Experiment 1976

In spite of very bad weather conditions, the first cruises of R.V. METEOR (4 - 17 March), of R.V. GAUSS (3 - 25 March), and of R.V. VICTOR HENSEN (22 - 31 March) have been successfully terminated.

R.V. METEOR started again for the Fladen Ground an March 23, one day behind schedule. She is working inside the FLEX box since March 25, the programme being slightly reduced because of 7 - 8 Beaufort. She had contact with R.V. VICTOR HENSEN and R.V. ARGOS.

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1) It would be appreciated if those who have received this document could copy the relevant parts for their colleagues who are interested. A limited number of copies is also available in Hamburg

The "MECHELEN" started her cruise, according to plan, on 2o March but, because of the bad weather, she could not yet begin her work in the FLEX area. She stands by near the Scottish coast waiting for better weather conditions.

As reported from R.V. METEOR, the plankton bloom has not yet started. The meteorological buoy of Mooring No. 25 (= J 76 94) near the centre of the FLEX box has dissappeared. Ships have been informed.

For further news see Annex 5.

2. Aerial Survey Base

The aerial survey group will be on stand - by at Sumburgh, Shetlands, from 2 April to about 7 May.

Adress: R. Doerffer or V. Amann (DFVLR)
c/o Sumburgh Airport Hotel
Sumburgh, Shetlands
Great Britain.
Telephone (Hotel): 2o 123
Telex: 75 355

3. Cruise Reports and Inventories

The Chief Scientists of the FLEX 76 vessels are invited to send a copy of their cruise reports and inventories to the Project Manager.

Annexes:

1. List of FLEX 76 Ships
(Amendments to Annex 1 of FLEX Information 4)

2. Instructions for Nutrients Intercalibrations
(by R. Johnston) (Copies of this document have earlier been distributed to Pichot, Eberlein, Weichart, Spencer, Gieskes, Ramster).

3. Cruise Programme of R.V. ANTON DOHRN (by H. Weidemann)

4. Programme of Cruise II of R.V. FRIEDRICH HEINCKE (by H. Weidemann and M. Gillbricht).

5. JONSDAP 76 - Aberdeen Communications Centre:

   Bulletin No 1; 24 March 1976
   (by H.D. Dooley).

6. Cruise Programme for R.V. CIROLANA, 1 - 6 ? May to 14 May (by R. Williams)

Annex 1

FLEX 76: List of Ships

(Amendments to Annex 1 of
FLEX Information 4)

CALL SIGN	SHIP	CRUISE SCHEDULE (PORT-TO-PORT DATES)	CHIEF SCIENTIST	TRANSMITTER FREQUENCIES	RECEIVER FREQUENCIES
DBYE	WALTER VON LEDEBUR (instead of MAX WALDECK)	2 - 23 June (London - Kiel)	Schunk	HF 1.5 - 24 MHz, A 3, A 1 MW 41o - 512 kHz, A 1, A 2 UHF 225 - 399 MHz VHF radio: 28 channels	
DSCZ (Telephony: charlie/ Zulu	PLANET	2o April - 7 May (Kiel - Bergen) 1o - 31 May (Bergen - London) 2 - 21 June (London - Kiel)	Schirmer Sellschopp Schunk	VHF air radio: 118.5 - 135 MHz (channel distance: 25 kHz) UHF air/ship: 225 - 399.5 MHz (channel distance: 5o kHz) HF 2 - 3o MHz, totally synthesized (A 1, A 3 and F 1 (RIT) - 5o/75 Band A 3 A, A 3 J, A 3 H) MF 41o - 512 kHz A 1, A 2 VHF radio: 57 channels	

Aberdeen 19.3.76

FLEX 1976 INSTRUCTIONS FOR NUTRIENTS INTERCALIBRATIONS

Frequency

A minimum of two intercalibrations for each mode of analysis employed should be worked by each ship on each visit.

A. Continuous analysis (sensitivity and zero error)

List nutrient results for 10km→ control station→ 10km (see Appendix A) also indicate the sensitivity of the analyzer for given levels of oxygen or nutrients.

B. Vertical profile, water-bottle samples (inter-ship comparison of results)

Each ship should collect from one sampler duplicate nutrient samples for vertical profiles worked at the control station. One set of samples should be passed to "Meteor" (or "Anton Dohrn") for analysis and in exchange a set of "Meteor" profile samples will be obtained.

On the second calibration, fill the duplicate set into "Meteor" bottles and collect your own bottles with a set of samples from"Meteor". (This should limit the disruption of sample bottle series.)

List your results as in Appendix B.

C. Calibration test ("Meteor" and other ships)
(Reproducibility, colour production)

"Meteor" will be checking nutrient calibrations against Sugawara standards but in general ICES Cooperation Research Report A29 will be followed.

Ships should report how zero nutrient is determined eg, distilled water or synthetic sea water.

Report also the best five successive calibrations using blank plus spike additions of standard solution, (see Appendix C) spread over one or several days.

If time allows do additional calibrations using nitrite to check nitrate conversion efficiency.

D. Preservation test (For those ships collecting and storing samples)

Work a vertical water-bottle profile at the central station, collecting samples in duplicate, from the same sampler. Pass one set to "Meteor" for immediate analysis (state nutrients for analysis) and collect a "Meteor" set. Preserve both sets in customary fashion.

Use Appendix B to report your results and give a brief account of the technique for preservation used.

Reporting back

The intercalibration exercise may well help to orientate the interpretation of the main Flex nutrients data bank. It will help everyone if Appendices A,B,C are compiled carefully and sent to Dr R Johnston, MARINE LABORATORY, P.O. BOX 101, VICTORIA ROAD, ABERDEEN, AB9 8DB, as soon as analyses are completed and checked.

A P P E N D I X A

Ship:-

Date:-

Observed content

Time	O_2	PO_4	NO_3	Si	Other
Position					
10Km N					
8					
6					
4					
2					
Central Stn.					
2Km S					
4					
6					
8					
10					
GMT					

Analyzer Sensitivity

$\frac{100\%\ O_2 \text{ saturation}}{}$ = scale divisions

$\frac{1/\text{ug-at } PO_4\text{-Pdm}^{-3}}{\text{(state colour units)}}$ =

$\frac{10/\text{ug-at } NO_3\text{-Ndm}^{-3}}{\text{(state colour units)}}$ =

$\frac{10/\text{ug-at } NO_2\text{-Ndm}^{-3}}{\text{(to check } NO_3 \rightarrow NO_2 \text{ efficiency)}}$ =

$\frac{5/\text{ug-at Sidm}^{-3}}{\text{(state colour units)}}$ =

A P P E N D I X B

Ship:-

Ships samples Date:- Date:-

Depth	Time	O_2	PO_4	NO_3	SiO_2	Time	O_2	PO_4	NO_3	SiO_2
0										
10										
20										
30										
40										
50										
75										
100										

"Meteor" samples Date:- Date:-

Depth	Time	O_2	PO_4	NO_3	SiO_2	Time	O_2	PO_4	NO_3	SiO_2
0										
10										
20										
30										
40										
50										
75										
100										

Preservation:- (1) Analysis date

(2) Outline of procedure

A P P E N D I X C

Ship:-

Nutrient Calibration - Phosphate (discrete samples)

1	2	3	4	5
Date	Date	Date	Date	Date
Time	Time	Time	Time	Time
Reading	Reading	Reading	Reading	Reading
Blank	Blank	Blank	Blank	Blank
+0.1	+0.1	+0.1	+0.1	+0.1
+0.2	+0.2	+0.2	+0.2	+0.2
+0.4	+0.4	+0.4	+0.4	+0.4
+0.6	+0.6	+0.6	+0.6	+0.6
+0.8	+0.8	+0.8	+0.8	+0.8

(Unit is), "Blank" is
spike should increase "Blank" by 0.1, 0.2 --- /ug at PO_4-P/l

Nutrient Calibration - Nitrate (discrete samples)

1	2	3	4	5
Date	Date	Date	Date	Date
Time	Time	Time	Time	Time
Reading	Reading	Reading	Reading	Reading
Blank	Blank	Blank	Blank	Blank
+1	+1	+1	+1	+1
+2	+2	+2	+2	+2
+4	+4	+4	+4	+4
+6	+6	+6	+6	+6
+8	+8	+8	+8	+8

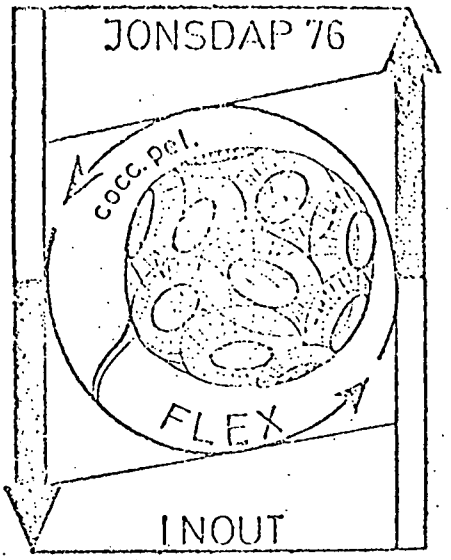
(Unit is), "Blank" is
spike should increase "Blank" by 1,2, --- /ug-at NO_3-N/l

Nitrate reduction efficiency:- 1. 2. 3. 4. 5.

Nutrient Calibration - Silicate (discrete samples)

1	2	3	4	5
Date	Date	Date	Date	Date
Time	Time	Time	Time	Time
Reading	Reading	Reading	Reading	Reading
Blank	Blank	Blank	Blank	Blank
+1	+1	+1	+1	+1
+2	+2	+2	+2	+2
+4	+4	+4	+4	+4
+6	+6	+6	+6	+6
+8	+8	+8	+8	+8

(Unit is), "Blank" is
spike should increase "Blank" by 1,2 --- /ug at Si/l



F L E X ' 7 6

Fahrtprogramm

FFS " ANTON DOHRN "

5. April - 7. Mai 1976

(Stand: 2o.3.76)

1. Die Aufgaben der "ANTON DOHRN" innerhalb FLEX'76

Die 189.(71.)Reise des FFS "ANTON DOHRN" ist ein Teil des Gesamtprogramms "FLEX'76". Dieses international koordinierte Experiment hat sich zum Ziel gesetzt, die biologisch-chemisch-physikalischen Vorgänge während der Frühjahrserwärmung und der ersten Planktonblüte im Seegebiet des Fladengrundes (nördliche Nordsee) möglichst lückenlos zu erfassen. Die so gewonnenen Daten sollen u.a. als quantitative Basis zur Entwicklung eines mathematischen Modells der Primärproduktion im Meere dienen.

Die Gesamtdauer des Experiments beträgt etwa 3 Monate (Mitte März bis Mitte Juni), die Zahl der teilnehmenden Schiffe aus 6 Ländern mehr als 15.

Während der etwa 5-wöchigen Beteiligung der "ANTON DOHRN" sind folgende Aufgaben vorgesehen:

a) im ersten und letzten Abschnitt (je etwa 1 Woche) wird nahe dem Zentrum der sogen. "FLEX-Box" - einem Gebiet von 1oo x 1oo km auf etwa 59°N und 1°E - je ein Vermischungs-Versuch mit dem Test-Farbstoff Rhodamin B durchgeführt. Parallel hierzu werden zweimal täglich Stationen mit Standard-messungen der hydrographisch-chemischen Parameter und Plankton-Schöpfproben gefahren, ergänzt durch Schleppfänge mit dem Zooplankton-Schließnetz.

b) Im mittleren Abschnitt von etwa 2 Wochen Dauer werden (während der Abwesenheit der "METEOR") viermal täglich Standard-Stationen der oben beschriebenen Art durchgeführt, und zwar um 0, 6, 12 und 18 Uhr Ortszeit.

c) Während dieses mittleren Abschnitts wird "ANTON DOHRN" auch die Funktion des Kommunikationszentrums zwischen den im Arbeitsgebiet anwesenden Schiffen sowie mit dem auf den Shetlands stationierten Forschungsflugzeug der DFVLR und mit der Landzentrale beim Marine Laboratory Aberdeen übernehmen. Hierbei handelt es sich um den täglichen Austausch von allgemeinen oder quantitativen (Daten-)Informationen, um die Abstimmung von Treffpunkten, Vergleichsmessungen, usw.

2. Vorläufiges Zeitprogramm

Mo, 29.3. bis Fr. 2.4.		Anliefern der Ausrüstung, Einbau der mit Werfthilfe an Deck zu befestigenden Ausrüstung (Container, Winde, Tank)
Sa. 3.4. So. 4.4.		(Ausrüstung und Beladung, soweit ohne Besatzungshilfe möglich)
Mo. 5.4.	11 Uhr	Auslaufen (Einschiffung der Teilnehmer spätestens eine Stunde vorher!)
Mi. 7.4.	früh	Eintreffen im Arbeitsgebiet, Kontaktaufnahme mit "METEOR". Probestationen aller Disziplinen, Schleppversuche mit Netz und "Delphin". Vorbereitung des Rhodaminversuchs.
Do. 8.4.	06 Uhr	Standard-Station
	09 Uhr	Ausbringen des Farbstoffs, Beginn des Vermischungsversuchs, Beobachtung der Entwicklung des Farbflecks.
	18 Uhr	Standard-Station (außerhalb des Farbflecks) Nachts Verfolgung der Rhodamin-Treibboje.
Fr. 9.4.	06 Uhr	Standard-Station
	ca.8-16h	Vermessung des Farbflecks, ggf. anschließend Aufnahme und wiederauslegung der Boje
	18 Uhr	Standard-Station
Sa.1o.4. bis Di.13.4.		(wie 9.4.)
Di.13.4.	18 Uhr	Standard-Station neben "METEOR", dabei Austausch von Personen und Material

Mi.14.4. bis ca.Mi.28.4.		Standard-Stationen um 0, 6, 12, 18 Uhr Zusammenarbeit mit "FRIEDRICH HEINCKE" (Bojenexperiment) durch Beobachtung der Treibbojen mit Radar. Zwischen den Stationen etwa einstündige Schleppfahrten mit "Delphin"(Chlorophyll-registrierung) und Schließnetz; dazwischen Abwasserabgabe in ausreichendem Abstand von der Zentralstation.
(ca.) Mi.28.4.		(bei Rückkehr der "METEOR"): Übergabe von Personen und Material
Mi.28.4.	09 Uhr	Ausbringen von Farbstofflösung, Beginn des zweiten Vermischungsversuchs.
Mi.28.4. bis Di. 4.5.		(Vermischungs-Vermessungen und halbtägliche Standard-Stationen wie 8.4.-13.4.)
Mi. 5.5.	06 h	letzte Station, ggf. Materialübernahme von "METEOR"
Mi. 5.5.	mittags	Ablaufen Richtung Cuxhaven
Fr. 7.5.	ca.08 h	An Cuxhaven Abgabe von Container, Winde, Tank und Zubehör Ausschiffung von Teilnehmern und sonstiger Ausrüstung.
	mittags	ab Cuxhaven
	abends	an Bremerhaven

3. Fahrtteilnehmer

Fahrtleiter: Dr.H.Weidemann, Dir.u.Prof., DHI Hamburg

Physikalische Ozeanographie, Vermischungsversuche:

Dr.Weidemann, H. Holzkamm, F. Tolkiehn, U. Wüstefeld, U.	DHI, Hamburg
Dr. Bartel Pries	Inst.f.Angew.Physik, Univ. Kiel

Meereschemie:

Dr. Weichart, G. Gumprecht, K. Schulz, Frl. Neubauer, Frl.	DHI, Hamburg

Meeresbiologie:

Prof.Dr.Gillbricht, M. Dr.Martens	Biol.Anstalt Helgoland
Kopp	Inst.f.Hydrobiologie Hbg.
Roßlenbroich	Fachber.Biologie,Fkft/M.
Dr. Joiris, C. van Thomme	Freie Universität Brüssel

Meteorologie:

Richter, B. Luthardt	Meteorologisches Inst. d.Univ.Hamburg

Arbeitsprogramm für F.K. "FRIEDRICH HEINCKE"

2. Teilfahrt vom 12.5. - 26.5.76

Während der zweiten Teilfahrt der "F.HEINCKE" ist eine Zusammenarbeit mit VFS "GAUSS" vorgesehen, die im gleichen Zeitraum im Zentralbereich des Arbeitsgebietes "FLEX-Box" (Fladengrund) Vermischungsversuche mit dem Farbstoff Rhodamin B durchführen wird. Während die "GAUSS" die Vermischung im Oberflächenbereich untersucht, wird von "F.HEINCKE" aus der gleiche Farbstoff in die Sprungschicht injiziert, um die Vermischnungsverhältnisse in dieser Tiefe zu studieren. Diese Arbeiten, die unter Leitung von Dr. G. Kullenberg (Institut für Physikalische Ozeanographie der Universität Kopenhagen) durchgeführt werden, erfordern es, daß das Schiff am Ort der Farbstoffausbringung treibt. Die Position wird dabei laufend registriert (Decca-Plotter bezw. Bojenpeilungen); die Farbstoffkonzentration wird dabei mit optischen Instrumenten gemessen, die in die Sprungschichttiefe gehängt werden.

Parallel zu diesen Hauptuntersuchungen sollen kontinuierliche Chlorophyllregistrierungen im Oberflächenwasser erfolgen (Wasserentnahme aus der Aquarienpumpe), und ferner werden einzelne Probenserien mit Wasserschöpfern entnommen, um die chemischen und Plankton-Untersuchungen des FLEX-Programms zu ergänzen.

Vorläufiger Zeitplan

12.5. morgens: Ab Helgoland
mittags: an Cuxhaven
Nachmittags: Beladung und Einschiffung
abends: ab Cuxhaven, Richtung Fladengrund

14.5. mittags: an Arbeitsgebiet "FLEX-Box"
nachmittags: Vorbereitungen und Erprobungen für die Experimente

15.5. bis 18.5.: erstes Experiment

18.5. abends: Ablaufen Richtung Aberdeen

19.5. mittags: an Aberdeen
nachmittags: Wasserübernahme; Materialübernahme von "METEOR"
abends: ab Aberdeen

20.5. mittags: an Arbeitsgebiet "FLEX-Box"
20.5. bis 24.5.: zweites Experiment
24.5. mittags: Ablaufen Richtung Cuxhaven
26.5. morgens: an Cuxhaven
vormittags: Entladen, Ausschiffung der Wissenschaftler
abends: an Helgoland

Fahrtteilnehmer

Fahrtleiter:	Dr.G. Kullenberg	Inst.f.Phys.Ozeanographie d.Universität Kopenhagen
	J.Hansen	
	Dr. G. Evans	Marine Laboratory, Aberdeen
	P.Mangelsdorf	BAH
	N.N.	IfM, Kiel
	N.N.	

(Stand: 15.3.76)

(Prof.Dr.H.Weidemann) (Prof.Dr.M.Gillbricht)

Verteiler :

An den Direktor der BAH, Herrn Prof.Dr.Kinne
Palmaille 9, 2000 Hamburg 50
An die Verwaltung der BAH, z.Hd. Herrn Kersten
Palmaille 9, 2000 Hamburg 50
An die Schiffseinsatzleitung der BAH, z.Hd.Herrn Dr.Moebus
An den Kapitän FK "FRIEDRICH HEINCKE", Herrn H.Falke
An Herrn Dr.G.Kullenberg, Institute of Physical Oceanography,
Haraldsgade 6, 2200 Copenhagen N, Dänemark
An Herrn H. Duchrow, SFB 94, Universität Hamburg,
Bundesstr./Sedanstr.,Baracke, 2000 Hamburg 13

Kopien an: DHI / Prof.Walden, Prof.Weidemann
BAH/ Prof. Gillbricht

JONSDAP 76 - ABERDEEN COMMUNICATIONS CENTRE

BULLETIN NO. 1 24 MARCH 1976

The purpose of this bulletin is to summarise progress in JONSDAP 76 and to provide information on the present status of moored buoys and of northern North Sea fishing and oil activities. Further editions will be produced whenever the need arises.

1. Moored buoys

a) All the moored stations were on position well before the deadline of 0000h on 15 March. Stations 32&37 were not deployed.

b) Stations 53 - 57 consist of 3 buoys each. One of the buoys at 53 has broken adrift and washed ashore at Colinsay, Orkney.

c) The buoys at 74 and 75 have also broken adrift and washed ashore at Stronsay and Sanday (Orkneys) respectively. The 74 buoy has been returned to Aberdeen. This buoy had broken adrift because the buoy wire had become caught on a sea bottom obstacle. No information is yet available regarding the other two buoys.

d) A seine net boat became caught on 40 on 21 March. Our informant tells us that the boat got clear but the surface buoy may be damaged.

2. Fishing activities

Very little trawling is going on in the mooring area except for intense Russian activity east of England. Two Scottish shrimp trawlers have been engaged on the Fladen and it is likely that this activity may increase. There is much seine net activity over a wide area, especially east of Orkney and Ling Bank.

3. Oil Activities

The vessel 'Explora' will be carrying out a seismic survey between 55°N and 62°N and 3°E and 4°W from 1 April for about 1 month. She will be towing a 2500 metre long cable and use airguns as the energy source. Attempts are being made to contact 'Explora' to make sure she knows about JONSDAP 76. Information is coming in on a large Rhodamine B project near the south western corner of the FLEX box and details will be provided when available.

4. The following message has been received from the JONSIS secretariat.

'Our very best wishes for the success of JONSDAP 76 -
Vivien Abrahams and John Bridger.'

H D Dooley

IMER/FLEX/4/76

VESSEL — R.V. CIROLANA

CRUISE PERIOD — 1-6? May to 14 May 1976

PERSONNEL

IMER, Edinburgh
R. Williams, PSO (Senior Scientist)
P.C. Reid, SSO
DAFS, Aberdeen
J. Dunn, SO

ITINERARY

The starting date and duration of the second leg of this cruise depends on the completion of the MAFF JONSDAP commitments during the first leg of this cruise.

Fri 30 April		Message from R.V. Cirolana to DAFS (Aberdeen) giving progress report on cruise and ETA at Aberdeen.
Tue 4 May		Probable docking date in Aberdeen.
Wed 5 May		R. Williams, P.C. Reid and equipment transported by laboratory vehicle to Aberdeen, load IMER and DAFS equipment aboard. Personnel sign on.
Thu 6		Sail Aberdeen (mid-day?). Start horizontal profiling equipment and meteorological observations. Proceed towards the FLEX square along the IN-OUT line ILSW at maximum cruising speed Start CPR tow when depth greater than 50m.
Fri 7 (4am)		Arrive centre of FLEX square Station 9 Work central station - two reversing water-bottle casts (9 depths). Oblique haul with HSLE system. LHPR oblique haul (06.00 hrs). Proceed towards Station 1.
	12.00	Arrive Station 1 Two reversing water-bottle casts (9 depths).
	13.00	Start HSLE grid (at 5 kts) and work Stations 2-8.
Tue 11 May (early am)		Complete HSLE grid and Station 8. Proceed towards Station 9.
	17.00	Arrive Station 9 Two reversing water-bottle casts (9 depths).
	18.00	LHPR oblique haul. Oblique haul with HSLE system. Proceed towards Station 1.
Wed 12 May (early am)		Arrive Station 1 and await arrival of R.V. Explorer. Two ship comparison (Chl$a$, Temperature, salinity and nitrate if possible) along grid track for as long as it is possible for CIROLANA to remain in the area.
Fri 14 May		Stop horizontal profiling equipment and meteorological observations. Dock Grimsby Official driver with laboratory vehicle to arrive Grimsby late afternoon. Unload equipment.

Sat 15 May IMER staff and equipment to travel back to Edinburgh

OBJECTIVES

The cruise has two main objectives:

1) To describe the horizontal variability of the physi chemical and biological processes over the FLEX square (see Fig. 1)
2) To describe the vertical variability of the physical chemical and biological processes at Stations near the margin and at the centre of the FLEX square.

There are three subsidiary objectives:

3) To make physical and chemical measurements and to sample the plankton along the IN-OUT line ILSW across the Orkney-Shetland inflow
4) To contribute to the collection of meteorological data as requested in Annex 111 of the report on the JONSDAP 76 meeting at Aberdeen
5) To make comparative measurements (temperature, chlorophyll a, nitrate and salinity) with R.V.Cirolana and R.V. Explorer steaming a small distance apart (~1km), either side by side or one behind the other, to study small to medium scale coherence of the horizontal variability at 3m.

PROCEDURES AND METHODS

1. The first objective will be met by making one quasi-synoptic survey of the FLEX square. The survey will consist of a pass over a 720km grid consisting of seven 90 km N-S legs, 15 km apart (Fig. 2). The pass will take approximately 4 days at 5 kts and the following measurements and samples will be taken:

   1.1 Temperature, salinity, in vivo chlorophyll a and nitrate at 3m using the ship's non'toxic sea-water supply (MAFF)
   1.2 Samples for chlorophyll a and phaeophytin from the pumped sea-water supply.(for calibration 2 per hour).
   1.3 Micro- and macrozooplankton samples taken by oblique hauls from near-bottom to surface at 5km intervals with the HSLE double net sampler (68µm and 250µm mesh) (DAFS).

2. The second objective will be met by working stations 1-9.

   The following measurements will be taken at every station:

   2.1 Temperature and salinity from water samples taken at depths (3, 10, 20, 30, 40, 60, 80, 100m and near bottom).

   2.2 Water samples from nine depths (see 2.1) for nitrate, nitrite, phosphate, silicate, chlorophyll a, phytoplankton cell counts and microzooplankton counts (all analysed ashore).

The/

The following samples will be taken from the central station only:

2.3 Micro- and macrozooplankton from near-bottom to surface by oblique hauls with the High Speed Loch Ewe (HSLE) double net sampler (68 and 250μm mesh) to determine C/N values, length/weight ratios and calorific values (IMER).

2.4 Zooplankton from near-bottom to surface by oblique hauls with the Longhurst Hardy Plankton Recorder (LHPR) with 5m depth resolutions (280μm mesh) (IMER).

3. The third objective will be met by taking measurements as in 1.1-1.2 and by towing a Continuous Plankton Recorder (CPR) while on passage between Aberdeen and the FLEX square.

4. The fourth objective will be met by:

4.1 Taking the following observations at hourly intervals whenever possible throughout the cruise.

Position	± 1nm
Wind speed and direction	± 1km, ± 1°
Air temperature	± 0.1°C
Humidity (or wet bulb temperature)	± 1% (± 0.1°C)
Sea surface temperature	± 0.1°C
Pressure	± 0.1 mb
Cloudiness	
Sea state	

Copies of the above measurements to:

Institut für Hydrobiologie und Fischereiwissenschaft, Universitat Hamburg, Palmaille 55, D-2000 Hamburg 50.

5. The fifth objective will be met by the two vessels R.V. CIROLANA and R.V. EXPLORER taking duplicate measurements with their horizontal profiling equipment hopefully for temperature, salinity, nitrate and chlorophyll a. The extent of this experiment will be decided upon when the ships are on station together.

EQUIPMENT REQUIRED

a) Supplied by MAFF, Lowestoft

Turner Fluorimeter
Autoanalyser/

Autoanalyser
Thermosalinograph
1 large domestic freezer
Precision depth recorder (0-200m)
6 NIO water bottles together with 12 protected thermometers (range at least 5-15°C), calibration certificates and 6 messengers
Meteorological Log Sheets
Bench Salinometer and standard sea water

b) Supplied by DAFS, Aberdeen

1 High Speed Loch Ewe sampling system and accessories

c) Supplied by IMER, Edinburgh

2 Longhurst Hardy Plankton Recorders with support gear
Salinity sample bottles
Nutrient vials (glass and polythene)
Filtering equipment, vacuum pump, storage jars, distilled water, formaldehyde
1 Continuous Plankton Recorder with support gear

For Figs. 1 and 2 see Annex 3/17 and 3/18 of FLEX Information 4.

Date: 17.3.76

Prepared by: R. Williams

Approved by: R.S. Glover

REPORT ON THE FLEX PLANKTON STUDIES WORKSHOP HELD AT THE MARINE LABORATORY, ABERDEEN, 30 OCTOBER - 3 NOVEMBER, 1975

By J.A. Adams,
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(Workshop Organizer)

1. INTRODUCTION

During the meeting of the ICES/JONSIS Working Group on JONSDAP 76 at De Bilt in June 1975, it was suggested that the various plankton studies proposed for FLEX 76 should be considered at a Workshop at Aberdeen. The present writer therefore arranged a Workshop which aimed to ensure, wherever possible:

(i) that the techniques used by the various institutes are standardised,
(ii) that arrangements are made to carry out intercalibration experiments,
(iii) that the programmes of the various institutes are complementary, and
(iv) that the maximum mutual assistance is arranged in the obtaining of, and the analysing of, data,

and it was with great pleasure that, on 30 October 1975, fourteen scientists at the Marine Laboratory welcomed nineteen other scientists (Appendix I) to Aberdeen.

The afternoon of 30 October and the whole of the 31 October were devoted to descriptions of the techniques which the various participants proposed to use during FLEX 76 while on the 1st, and for a short period on the 3rd, two sub-groups considered the proposed studies in greater detail. The two sub-groups then reported to a meeting of the whole Workshop and, following a general discussion, the Workshop closed at 1300 hours on the 3rd of November. Appendices II and III give respectively a summary of the programme and lists of the membership of the sub-groups.

No attempt has been made to present here summaries of the contributions given on the 30 and 31 October since some of the detail of these were necessarily changed by the subsequent discussions.

The writer must thank the Workshop participants; the success of the Workshop is entirely due to them. He must also thank P. Polk and R. Williams, who co-ordinated the activities of their respective sub-groups, while his special thanks must go to D.D. Seaton and H.G. Franse who had to produce written reports on the activities of the sub-groups in all-too-short a time. On their reports, the second section of this report is largely based.

2. DECISION AND RECOMMENDATIONS OF THE WORKSHOP

Decision and recommendations made by the two sub-groups have been combined to give a coherent account of the actions which will be taken by individuals or groups in preparation for, or during, FLEX 76 and of the factors which should be taken into account when the final details of the FLEX 76 programme are being decided upon. Some of the decision and recommendations were discussed further during the subsequent meeting of the ICES/JONSIS Working Group on JONSDAP 76 at Aberdeen on 4th-5th November and, where appropriate, information on these discussions is given as footnotes.

It is expected that, with a very few exceptions, the groups which have been given the task of agreeing the detail of various standardised methods will do so by letter, and that the methods which they recommend will be issued in a supplement (to this report) to be issued about mid-January 1976. It is hoped that the mid-January supplement will also include the descriptions of certain techniques which individuals have been asked to prepare for the benefit of FLEX participants.

2.1 Decisions Relating to Phytoplankton Studies

2.1.1 The measurement of Chlorophyll and other pigments

I.E. Baird, W.W. Gieskes, E. Hagmeier, K.J. Trahms and J.P. Mommaerts will consider the various techniques for the measurement of chlorophyll and other pigments and will provide details of the techniques which should be used.

2.1.2 Water bottle samples for phytoplankton cell counts

M. Gillbricht will provide details of how best to obtain water bottle samples for phytoplankton cell counts and of the Lugols solution to be used as a fixative and preservative.

M. Gillbricht believes that he will be able to analyse samples (250 ml) obtained by other participants but those who wish to send samples to M. Gillbricht should contact him as soon as possible.

2.1.3 Analyses of phytoplankton samples

When phytoplankton samples are analysed to give numbers of the various organisms (cell counts), the analyses should be done in such a way that, as a minimum, information is obtained on the total numbers of (i) diatoms, (ii) peridinians and (iii) other algae. By using suitable conversion factors (see 2.1.4) these data can then be converted to standing stock data for each of these three groups in terms of dry weight or carbon.

More detailed analyses should of course be done whenever possible.

The phytoplankton species likely to be found in the FLEX box will be included in the list being prepared by R. Williams (see 2.4.1).

2.1.4 Phytoplankton cell volume to carbon relationships

W.W. Gieskes, M. Gillbricht, E. Hagmeier and J.P. Mommaerts will decide upon a standardised method for converting phytoplankton cell volume measurements to carbon values.

2.1.5 Measurement of primary productivity rates using C^{14}

I.E. Baird, W.W. Gieskes, E. Hagmeier and J.P. Mommaerts will discuss standardisation of the C^{14} technique and the construction and testing of a standard incubator with a standard set of filters. This incubator will be used by all FLEX participants. They will also agree upon a standard method for the measurement of light and will arrange for the intercalibration of filtering and counting techniques.

2.1.6 Phytoplankton respiration

J.H. Hecq will measure the respiration of phytoplankton (see also 2.2.8 and 2.3.2). These studies will be done on board "Mechelen". He will also freeze samples of phytoplankton for carbohydrate and protein analyses.

2.1.7 Kinetics of nutrient uptake

J.M. Davies will make measurements of the kinetics of nutrient uptake by phytoplankton during a part of the "John Murray" cruise and a part of the "Scotia" cruise.

2.2 Decisions Relating to Zooplankton Studies

2.2.1 The dry weight of zooplankton samples

J.A. Adams will provide details of the methods which should be used to freeze and dry zooplankton samples for dry weight determinations.

2.2.2 Sub-sampling of zooplankton samples which are to be frozen

Whenever possible, sub-samples will be obtained from zooplankton samples which are to be frozen. These sub-samples will be obtained using methods to be circulated by J.A. Adams and will be fixed and preserved in formaldehyde for future analyses (see 2.2.4). By using appropriate conversion factors (see 2.2.5) the data obtained from the analyses of these sub-samples should enable estimates to be made of the standing stocks of herbivores, omnivores and carnivores as opposed to the total zooplankton standing stock data which will be obtained from the frozen part of the samples. In addition, the analyses of the sub-samples will also provide data on the abundance of the various species and if time is not available to analyse the sub-samples completely, they should be kept for future reference.

2.2.3 Microzooplankton

K.J. Trahms will filter five litres of water through 30 µ mesh to obtain samples of the microzooplankton. At selected stations he will also use 50 µ and 68 µ mesh filters so that his data may more readily be compared with the data obtained by the Marine Laboratory, Aberdeen and the Nederlands Instituut voor Onderzoek der Zee.

2.2.4 Analyses of zooplankton samples

When zooplankton samples are analysed to give numbers of the various organisms, the analyses should be done in such a way that, as a minimum, information is obtained on the total numbers of (i) herbivores, (ii) omnivores and (iii) carnivores. By using suitable conversion factors (see 2.2.5) these data can then be converted to standing stock data for each of these three groups in terms of dry weight or carbon.

More detailed analyses should however be done whenever possible.

The classification of zooplankters as herbivores, omnivores and carnivores will be according to the plankton check list being prepared by R. Williams (see 2.4.1).

2.2.5 The chemical composition of zooplankters and weight to length relationships

Throughout the period of FLEX 76, R. Williams and H. Weikert will freeze representative zooplankters for a study of the chemical composition of zooplankters and weight to length relationships. In addition, calorific values will also be determined.

The zooplankters will be prepared at sea using a method to be described by R. Williams. These studies will provide weight to length conversion factors etc which will be used by all participants for converting from numbers of zooplankters to weights etc.

2.2.6 Co-operation on the study of the vertical distribution of zooplankton

H. Weikert, M. Bossicart and R. Williams will contact each other prior to FLEX 76 to consider further the possibilities of co-operation with regard to their studies of the vertical distribution of zooplankton.

2.2.7 Intercalibration of zooplankton samplers

Participants using zooplankton samplers will arrange, whenever possible, to intercalibrate them during suitable FLEX 76 cruises.

2.2.8 Zooplankton respiration

J.H. Hecq will measure the respiration of zooplankton (see also 2.1.6 and 2.3.2). These studies will be done on board "Mechelen".

2.2.9 Preparation for zooplankton grazing experiments

N. Polk-Daro and O. Cromboom will visit the Marine Laboratory, Aberdeen, during January 1976 so that they may demonstrate their C^{14} technique for measuring zooplankton grazing and, at the same time, familiarise themselves with the Coulter Counter technique used at Aberdeen. Experiments will be carried out to compare the results of the two techniques.

2.2.10 Ammonia analysis of water from grazing experiments

On occasions water samples from grazing experiments will be frozen for subsequent ammonia analysis.

2.3 Decisions Relating to Studies of Bacteria

2.3.1 Bacterial activity

C. Joiris will measure the respiration of bacteria (as an indicator of bacterial activity) and the direct incorporation of radio-active organic matter. He will intercalibrate his techniques with those of the German bacteriologists prior to FLEX 76 and will liaise with other participants measuring the respiration of phytoplankton and zooplankton.

2.3.2 Bacterial respiration

J.H. Hecq will measure the respiration of bacteria (see also 2.1.6 and 2.2.8). These studies will be done on board "Mechelen".

2.4 Decisions Relating to General Aspects

2.4.1 Plankton check list

R. Williams will co-ordinate the preparation of a check list of the zooplankton of the North Sea[1]. By correspondence with other participants he will (i) ensure, as far as practicable, that the list is exhaustive, (ii) indicate those species which are likely to be most important ecologically in the FLEX box, (iii) indicate which species should be considered as herbivores, which should be considered as omnivores and which as carnivores and (iv) decide on any size criteria which may be necessary (e.g. small herbivores, large herbivores).

2.4.2 The operation of the survey vessels in relation to the "Meteor"

The vessels which carry out the large scale surveys of the FLEX box will work a grid with fixed geographical co-ordinates but will return to the central[2] position at the end of each survey of the grid for additional sampling.

2.4.3 Updated information on research programmes and ships' dates

Updated information on research programmes and ships' dates will be summarised in tabular form and supplied to H. Duchrow by early December 1975.

2.4.4 Data management

It was agreed that the Workshop participants would follow the recommendations of the Data Management Sub-Group. It was believed that the raw data on photosynthetic rates, grazing rates, respiration rates and excretion rates would be available at least in some initial form at the end of the six months while the final data should be available at the end of twelve months.

Plankton standing stock data should also be available at the end of six months, but the results of the detailed analyses would not be available until the end of twelve months at the earliest.

2.5 Recommendations Relating to Phytoplankton

2.5.1 Exchange of aliquots of sea water for the intercalibration of techniques

It was recommended that aliquots from large samples of sea water (taken at fortnightly intervals throughout the FLEX programme) should be distributed for the intercalibration of the techniques for the measurement of organic carbon, chlorophyll, nutrients and C^{14} uptake.

Footnotes

(1) The original intention was that the check list should list only the plankton of the FLEX box. However, since the JONSDAP 76 data set will include data from the whole of the northern North Sea and since computer codes are to be allocated to each entity on the list, it has been decided that the check list should be for the plankton of the whole North Sea, thus laying the foundations of a system which could be used for the computerised storage of North Sea plankton data for future years.

(2) During the Workshop and during the subsequent meeting of the ICES/JONSIS Working Group on JONSDAP 76, there was much discussion of whether the "Meteor" and associated vessels should be moored or drifting and, if drifting, of how the position from which she would drift should be chosen. It appears that "Meteor" will drift from the centre of the FLEX box and return to that position if she drifts too far.

2.5.2 Intercalibration of nutrient analysis techniques prior to FLEX 76

The Workshop recommended that chemists participating in FLEX 76 should be asked to intercalibrate the nutrient analysis techniques prior to FLEX 76(1).

2.5.3 Sinking rates of phytoplankton

Noting that Dr Schöne had withdrawn from the FLEX 76 programme, the Workshop recommended that an attempt should be made to encourage another scientist or scientists to study sinking rates of phytoplankton.(2).

2.6 Recommendations Relating to Zooplankton

2.6.1 The study of the vertical distribution of zooplankton from the drifting vessel

Noting that the time which appeared to be available for the study of the vertical distribution and migration of zooplankton from the drifting vessel was inadequate, and agreeing that the obtaining of these data for the whole of the period of the FLEX 76 study was highly desirable, the Workshop recommended that every effort should be made to provide (i) the necessary time for sampling every six hours (see 2.7.2) and (ii) space for appropriate staff on the "Meteor" or another suitable vessel. Furthermore, noting that H. Weikert had only one sampler, the Workshop recommended that he should try to obtain a second one.

2.6.2 Facilities for the study of zooplankton grazing rates

Agreeing that data on zooplankton grazing rates should be obtained from the drifting vessels for the whole of the FLEX 76 programme, the Workshop recommended that facilities should be provided on the "Meteor" for two people for these studies(3) for the whole period of FLEX 76.

Footnotes

(1) See Appendix IV to the report of the subsequent meeting of the ICES/JONSIS Working Group on JONSDAP 76.

(2) At the subsequent meeting of the ICES/JONSIS Working Group on JONSDAP 76, it was agreed that this should only be done if shipboard facilities could be provided without reducing the facilities which should be given for studies of zooplankton vertical distribution and grazing.

(3) Discussion at the subsequent meeting of the ICES/JONSIS Working Group on JONSDAP 76 showed that it would be difficult to meet both H. Weikert's needs and those of the Scottish and Belgain participants interested in zooplankton grazing rates. J.C. Gamble, N. Polk-Daro and H. Duchrow are at present trying to reach a solution to this problem.

If "Scotia" is available the Scottish participants will also carry out zooplankton grazing experiments from this vessel.

2.6.3 The natural mortality of zooplankton

Noting that no adequate study of the natural mortality of zooplankton was proposed, the Workshop recommended that an attempt should be made to encourage such a study[1].

2.7 Recommendations Relating to General Aspects

2.7.1 Vertical sampling depths

The Workshop recommended (i) that vertical sampling should include samples from the surface film (if practicable), 3 metres, 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90m, 100m, 125m and bottom; (ii) that additional or alternative depths should be sampled if continuous profiling systems show this to be desirable; and (iii) that, lest time or facilities are limited, a list should be prepared of high priority depths for the obtaining of various measurements.

2.7.2 Daily sampling frequency

The Workshop recommended that the minimum daily sampling frequency should be based on a six hours time interval, with sampling around 0600 hours, 1200 hours, 1800 hours and 2400 hours. If an event of particular interest occurs, the sampling interval should be reduced to a two or four hour interval.

2.7.3 Communication of information

The Workshop recommended that information should be transmitted daily on thermocline depth, chlorophyll a, and zooplankton settled volumes using the communication system to be set up by H. Duchrow.

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(1) The comments made in the footnote to 2.5.3 would also apply to this recommendation.

APPENDIX I

PARTICIPANTS

From Department of Agriculture and Fisheries for Scotland
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A.R. Kiby
R. Williams

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Fisheries and Food
Fisheries Laboratory,
Lowestoft.

J.W. Horwood

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H. Duchrow (FLEX 76 Project Manager)

APPENDIX II

SUMMARY OF FLEX PLANKTON STUDIES WORKSHOP PROGRAMME

30 October

J.A. Adams, J.H. Steele and P. Polk Introductory remarks.

R. Williams and R.H. Bruce Annual fluctuation of plankton in area B2, 1948-1974 and 1958-1974. CPR and UOR phytoplankton programme.

M. Gillbricht Sampling phytoplankton with water bottles.

I.E. Baird Chlorophyll measurement.

K. Jürgen Trahms In-situ-fluorometer as used from "Anton Dohrn" on Fladen Ground in July 1975.

W.W. Gieskes Turner fluorometry, continuous turbidometry, and thin-layer chromatography.

J.P. Mommaerts Pigment analysis.

J.C. Gamble Use of Coulter counter.

31 October

R. Williams and R.H. Bruce CPR, UOR and LHPR zooplankton programme.

H.G. Fransz High-speed zooplankton sampling.

J.A. Adams A high-speed zooplankton sampler.

H. Weikert Multiple opening-and-closing net. Physical and chemical techniques for working up zooplankton.

E. Hagmeir Measurement of primary productivity.

W.W. Gieskes Primary productivity.

J.P. Mommaerts Photosynthesis, excretion of phytoplankton, and enrichment.

J.C. Gamble Grazing and excretion by zooplankton.

N. Polk-Daro and O. Cromboom Grazing and nutrient excretion by zooplankton and the effect on phytoplankton production.

J.H. Hecq Measurement of zooplankton respiration.

J.M. Davies Deployment of settlement traps and the analysis of material collected.

C. Joiris Heterotrophic aerobic planktonic bacteria: activity measurements.

J.H. Steele, G. Pichot, J.P. Mommaerts and J.W. Horwood Ecosystem models.

1 November

Meetings of the sub-groups.

3 November

Meetings of the sub-groups followed by the presentation of their reports to the Workshop.

General Discussion.

APPENDIX III

SUB-GROUP ON THE DESCRIPTION OF PHYTOPLANKTON AND ZOOPLANKTON POPULATIONS

J.A. Adams
M. Bossicart
R.H. Bruce
D.V.P. Conway
J. Dunn
H.G. Fransz (Rapporteur)
M. Gillbricht
N.T. Nicoll
K.J. Trahms
H. Weikert
R. Williams (co-ordinator)

SUB-GROUP ON THE MEASUREMENT OF RATES

I.E. Baird
O. Cromboom
J.M. Davies
H. Duchrow
G.T. Evans
B. Frost
J.C. Gamble (Joint Rapporteur)
W.W. Gieskes
E. Hagmeier
S.J. Hay
J.H. Hecq
A.R. Hiby
C. Joiris
J.P. Mommaerts
G. Pichot
P. Polk (co-ordinator)
N. Polk-Daro
D.D. Seaton (Joint Rapporteur)
J.H. Steele

List of Publications and Reports

Supported by Contract AT(11-1)-3566
Formerly AT(30-1)-4150

NYO-4150-1 Sachs, P. L. and D. W. Spencer (1970)
In situ measurement of light scattered from a laser beam compared to suspended particulate concentrations derived from concurrently collected samples

W.H.O.I. Technical Report

NYO-4150-2 The distribution of some chemical elements between dissolved and particulate phases in the ocean

Report to AEC on Contract AT(30-1)-4150, 1969-70

NYO-4150-3 Turner, J. S., T. G. Shirtcliffe and P. G. Brewer (1970)
Variations of transport coefficients across density interfaces in multiple diffusive systems

Nature, 228, 1083

NYO-4150-4 Spencer, D. W., D. E. Robertson, K. K. Turekian and T. R. Folsom (1970)
Trace element intercalibrations and profiles at the GEOSECS test station in the northeast Pacific Ocean

J. Geophys. Res., 75, 7688

NYO-4150-5 Brewer, P. G. and D. W. Spencer (1970)
Trace element intercalibrations study

W.H.O.I. Technical Report No. 70-62

NYO-4150-6 Brewer, P. G. and D. W. Spencer (1971)
Colorimetric determination of manganese in anoxic waters

Limnol. & Ocean., 16, 107

NYO-4150-7 Spencer, D.W. and P. G. Brewer (1971)
Vertical advection, diffusion and redox potentials as controls on the distribution of Mn and other trace metals dissolved in waters of the Black Sea

NYO-4150-8 Spencer, D. W., P. G. Brewer and P. L. Sachs (1971)
Aspects of the distribution and trace element composition of suspended matter in the Black Sea

Geochim. et Cosmochim. Acta, 36, 71

NYO-4150-9 Distribution of some chemical elements between dissolved and particulate phases in the ocean

Report to AEC on Contract AT(30-1)-4150, 1970-71

COO-3566-1 Brewer, P. G. and D. W. Spencer (1972)
The distribution and flux of some trace elements between dissolved and particulate phases in the Black Sea

"The Black Sea-Geology, Chemistry and Biology" E. T. Degens and D. A. Ross, eds., AAPG Memoir 20, p. 137-143.

COO-3566-2 Brewer, P. G., D. W. Spencer and D. E. Robertson (1972)
Trace element profiles from the GEOSECS test station in the Sargasso Sea

Earth & Planet. Sci. Lett., 16, 111-116

COO-3566-3 Distribution of some chemical elements between dissolved and particulate phases in the ocean

Report to AEC on Contract AT(11-1)-3566, 1971-72

COO-3566-4 Distribution of some chemical elements between dissolved and particulate phases in the ocean

Report to AEC on Contract AT(11-1)-3566, 1972-73

COO-3566-5 Brewer, P. G. and J. W. Murray (1973).
Carbon, nitrogen and phosphorus in the Black Sea

Deep Sea Res., 20, 803-818

COO-3566-6 Murray, J. W. (1974)
The Surface Chemistry of Hydrous Manganese Dioxide

J. Colloid and Interface Science, 46, 357

C00-3566-7 Brewer, P. G.
Warming of deep water in the Cariaco Trench

In preparation

C00-3566-8 Murray, J. W. (1975).
The Interaction of Cobalt with Hydrous Manganese Dioxide

Geochim. et Cosmochim. Acta (in press)

C00-3566-9 Murray, J. W. (1975).
The Interaction of Metal Ions at the Manganese Dioxide-Solution Interface

Geochim. et Cosmochim. Acta, 39, 505, 519

C00-3566-10 The Distribution of Some Chemical Elements Between Dissolved and Particulate Phases in Sea Water

Report to AEC on Contract AT(11-1)-3566, 1973-74.

C00-3566-11 The Distribution of Some Chemical Elements Between Dissolved and Particulate Phases in Sea Water

Report to AEC on Contract AT(11-1)-3566, 1974-75

C00-3566-12 Brewer, P. G. (1975)
Minor Elements in Sea Water. In "Chemical Oceanography", Vol. 1, Second Edition, J. P. Riley and G. Skirrow, Eds., Academic Press, London

C00-3566-13 Brewer, P. G. and Spencer, D. W. (1975)
Minor Element Models in Coastal Waters. In "Marine Chemistry in the Coastal Environment", A.C.S. Symposium Series Volume. T. M. Church, ed., v. 18, 80-96.

COO-3566-14 Bacon, M. P. (1975). Applications of Pb-210/Ra-226 and Po-210/Pb-210 disequilibria in the study of marine geochemical processes. Ph.D. Thesis, WHOI-MIT Joint Program.

COO-3566-15 Bacon, M. P., D. W. Spencer and P. G. Brewer (1976). Pb-210/Ra-226 and Po-210/Pb-210 disequilibria in sea water and suspended particulate matter. E.P.S.L. (submitted).

COO-3566-16 Bacon, M. P. (1976). Pb-210 and Po-210 results from F. S. "Meteor" Cruise 32 in the North Atlantic. Kiel. Meersf. (submitted).

COO-3566-17 The distribution of some chemical elements between dissolved and particulate phases in sea water. Report to ERDA on Contract AT(11-1)-3566 1975-76.